Samsung Electronics Co., Ltd. et al. v. XiFi Networks R&D, Inc.

Petitioners' Demonstratives

Hearing: October 7th and 8th, 2026

Summary of Grounds

IPR No.	Patent No.	Combination
IPR2025-01203	11,849,337	Chincholi, Riggert
IPR2025-01204	11,818,591	Chincholi, Riggert
IPR2025-01205	12,003,976	Chincholi, Riggert, Clegg
IPR2025-01206	11,950,105	Chincholi, Riggert, Clegg
IPR2025-01207	12,015,933	Chincholi, Riggert, Clegg
IPR2025-01208	11,974,143	Chincholi, Riggert (+Choi (Ground 2))
IPR2025-01209	11,856,414	Chincholi, Riggert (+Choi (Ground 2))
IPR2025-01270	12,114,177	Chincholi, Clegg
PGR2025-00067	12,190,198	Chincholi, Clegg
PGR2025-00068	12,169,756	Chincholi, Clegg
PGR2025-00069	12,250,564	Chincholi, Choi, Clegg

Summary of Section 103 Disputed Issues

Issue	IPR-01203	IPR-01204	IPR-01205	IPR-01206	IPR-01207	IPR-01208	IPR-01209	IPR-01270	PGR-00067	PGR-00068	PGR-00069
§103: “virtual MAC interface”	X	X	X	X	X	X	X	X	X	X	X
§103: “bandwidth availabilities”	X	X	X	X	X	X	X	X	X	X	X
§103: “transparent”	X	X	X	X	X	X	X	X	X	X	X
§103: “does not prevent”	X	X	X	X	X	X	X	X			X
§103: “without requiring disassociation	X	X	X	X	X	X	X	X			X
Motivation to Combine	X	X	X	X	X	X	X	X	X	X	X

Background

Background

- Modern Network architectures use "stacks of layers":

> "To reduce their design complexity, most networks are organized as a stack of layers or levels, each one built upon the one below it. The number of layers, the name of each layer, the contents of each layer, and the function of each layer differ from network to network. The purpose of each layer is to offer certain services to the higher layers while shielding those layers from the details of how the offered services are actually implemented. In a sense, each layer is a kind of virtual machine, offering certain services to the layer above it."

Ex. 2010 (Tanenbaum) at 45

> "A list of the protocols used by a certain system, one protocol per layer, is called a **protocol stack**."

Ex. 2010 (Tanenbaum) at 47

Background

- Examples of different types of network architectures:

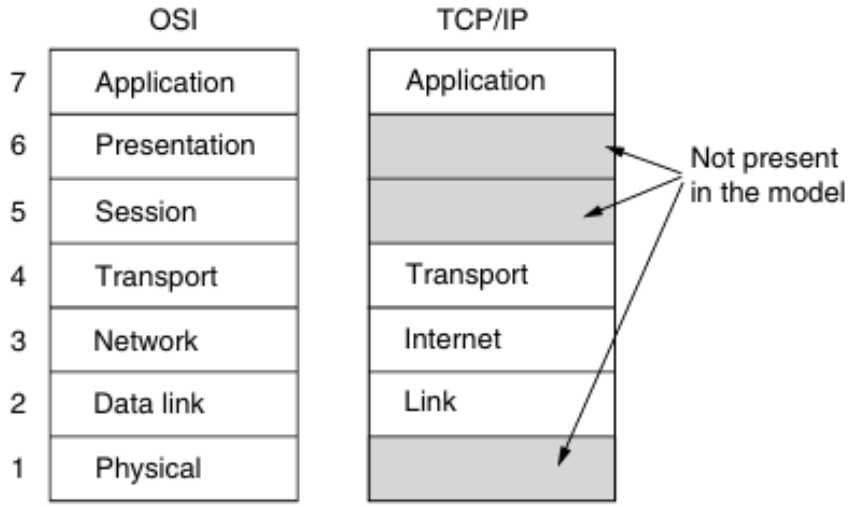
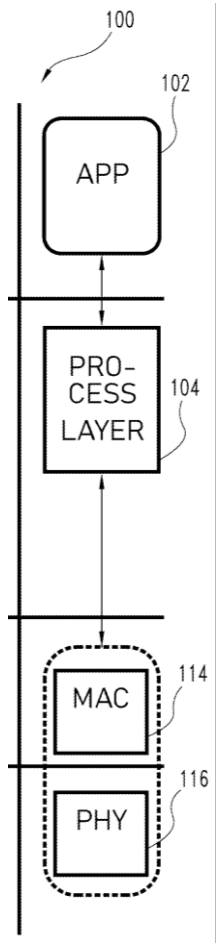


Figure 1-21. The TCP/IP reference model.

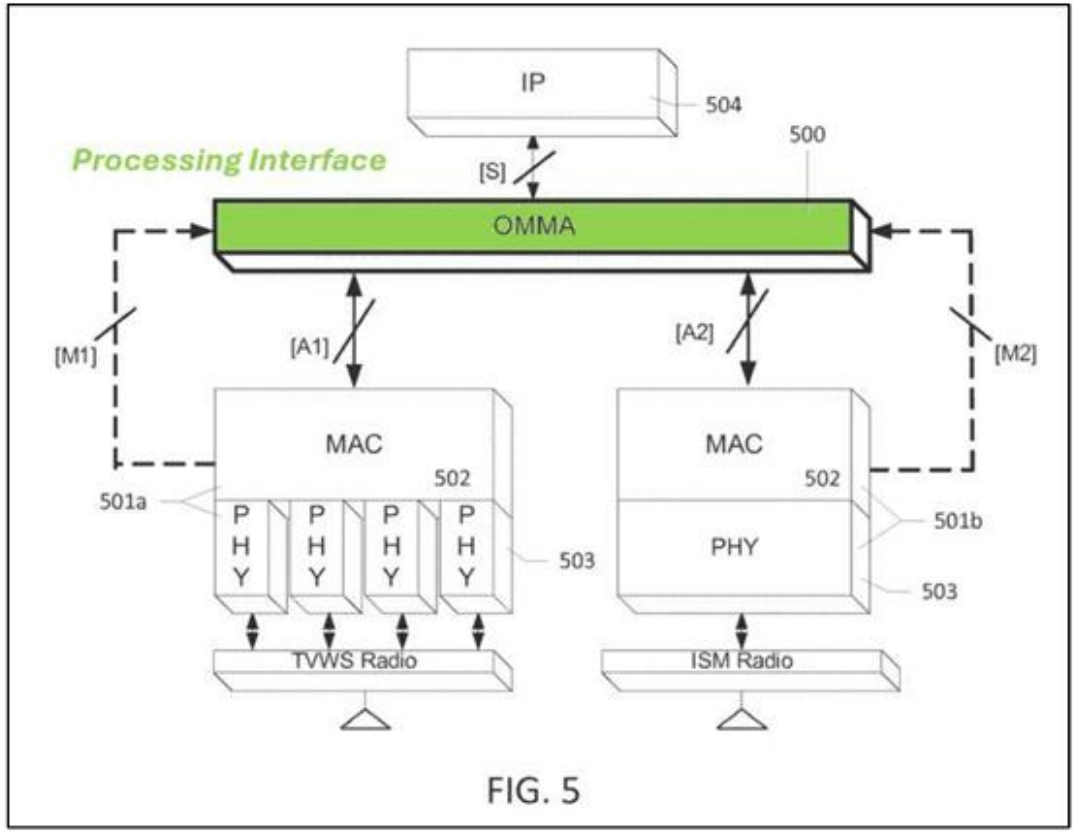
Ex. 2010 (Tanenbaum) at 62

Background

- Examples of different types of network architectures:



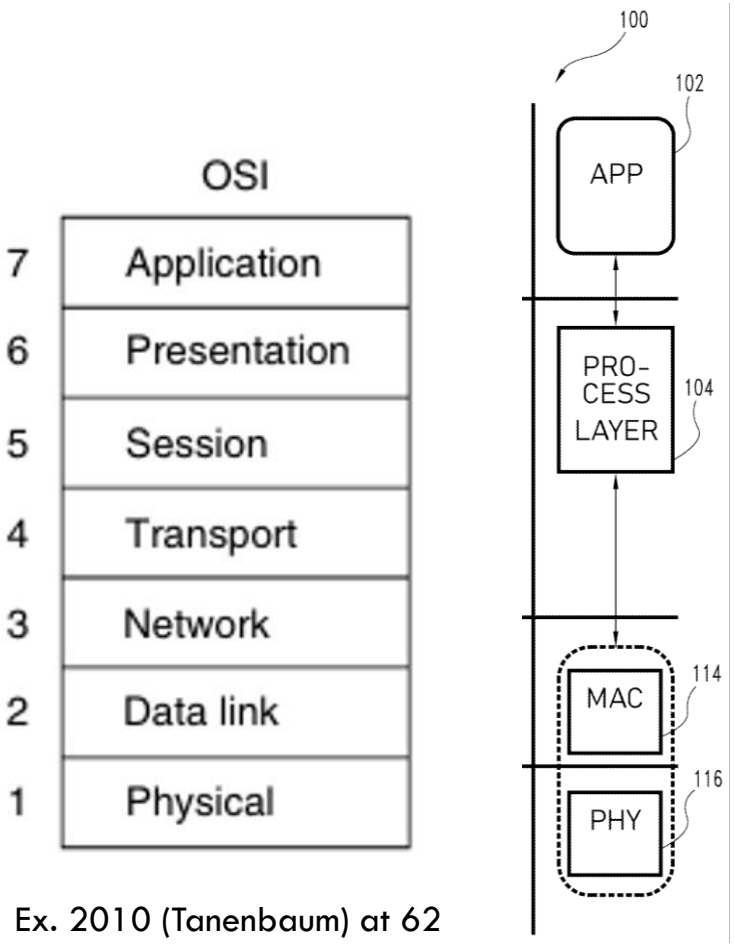
Ex. 1001 (564 patent) at Fig. 1



Ex. 1005 (Chincholi) at Fig. 5 (annotated)

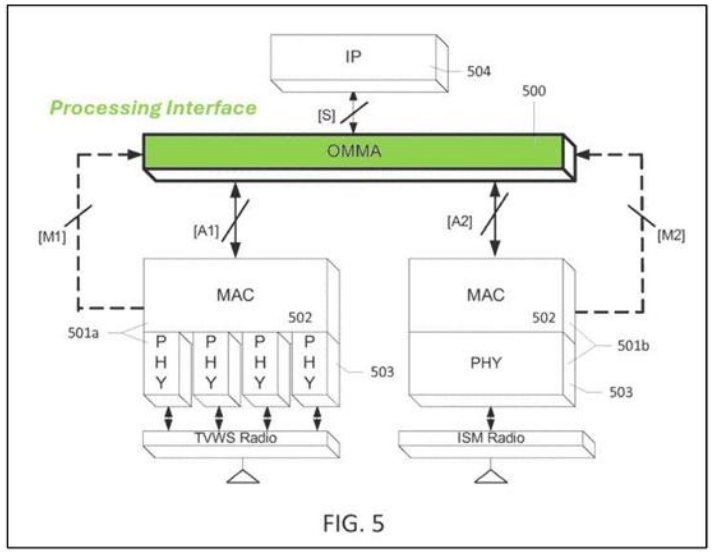
Background

- Examples of different types of network architectures



Ex. 2010 (Tanenbaum) at 62

Ex. 1001 (564 patent) at Fig. 1



Ex. 1005 (Chincholi) at Fig. 5 (annotated)

"[A]lthough the claim recites connections among the processing interface, application interface, and actual MAC/PHY interfaces, it does not require the processing interface to be adjacent to the physical layer or located in any particular layer of the OSI model."

Ex. 1026 (Almeroth Supp. Decl.) at ¶26; Reply 3

"[T]he claims do not recite the OSI model, Layer 2, the MAC sublayer, adjacency to the PHY layer, or any other specific protocol-stack location for the processing interface, virtual MAC interface, or resource monitoring interface."

Ex. 1026 (Almeroth Supp. Decl.) at ¶116; Reply 20

Background

- OSI and TCP/IP reference models

"The main task of the data link layer is to transform a raw transmission facility into a line that appears free of undetected transmission errors. It does so by masking the real errors so the network layer does not see them. It accomplishes this task by having the sender break up the input data into data frames (typically a few hundred or a few thousand bytes) and transmit the frames sequentially. If the service is reliable, the receiver confirms correct receipt of each frame by sending back an acknowledgement frame. …
Broadcast networks have an additional issue in the data link layer: how to control access to the shared channel. A special sublayer of the data link layer, the medium access control sublayer, deals with this problem."

Ex. 2010 (Tanenbaum) at 59

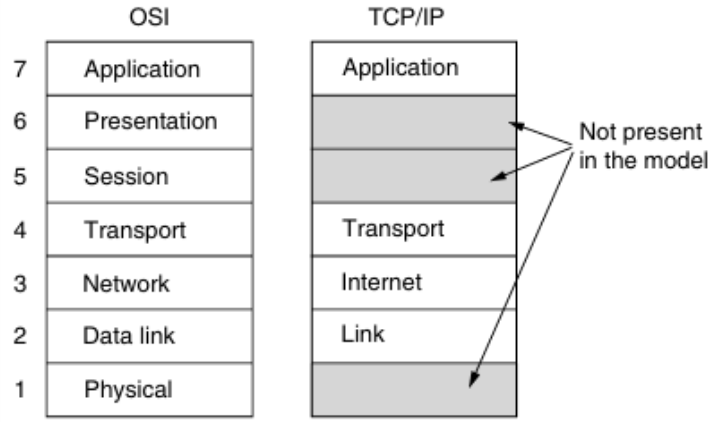


Figure 1-21. The TCP/IP reference model.

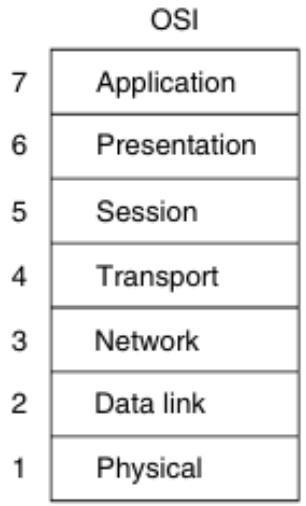
Ex. 2010 (Tanenbaum) at 62

"All these requirements led to the choice of a packet-switching network based on a connectionless layer that runs across different networks. The lowest layer in the model, the link layer describes what links such as serial lines and classic Ethernet must do to meet the needs of this connectionless internet layer. It is not really a layer at all, in the normal sense of the term, but rather an interface between hosts and transmission links. Early material on the TCP/IP model has little to say about it."

Ex. 2010 (Tanenbaum) at 62

Background

- OSI Reference Model



Ex. 2010 (Tanenbaum) at 62

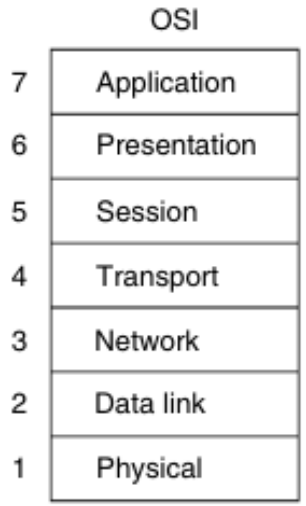
Application Layer:

- Protocols commonly needed by users
- Examples include HTTP, SFTP, Mail
- E.g., when a web browser communicates with a web server, packets are formatted in the HTTP protocol

Ex. 2010 (Tanenbaum) at 59-61

Background

- OSI Reference Model



Ex. 2010 (Tanenbaum) at 62

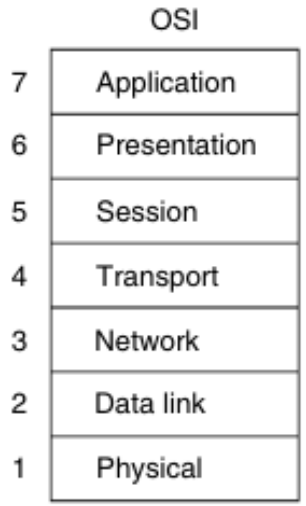
Presentation Layer:

- Defines the syntax and semantics of transmitted information
- Converts application data into defined data structures to send over the wire
- Defines which character encoding to use (e.g. ASCII, Unicode)

Ex. 2010 (Tanenbaum) at 59-61

Background

- OSI Reference Model



Ex. 2010 (Tanenbaum) at 62

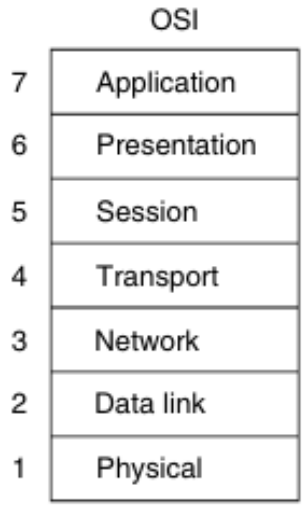
Session Layer:

- Allows different machines to establish sessions between them
- Defines how the machines keep track of whose turn it is to transmit
- Defines how the machines prevent attempts of simultaneous operations
- Synchronizes machines if one of them disconnects
- Sessions outlasts / spans multiple transport layer connections

Ex. 2010 (Tanenbaum) at 59-61

Background

- OSI Reference Model



Ex. 2010 (Tanenbaum) at 62

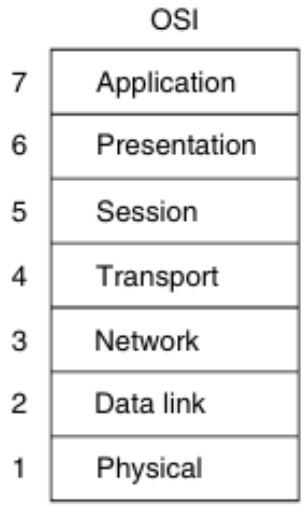
Transport Layer:

- Defines which transport protocol to use to transfer packets
- Can split up packets into smaller units if needed
- Ensures packets arrive at destination correctly, and in order
- True end-to-end layer
  - Lower layers handle routing
- Defines the service the transport protocol will use (e.g. point-to-point or broadcast)

Ex. 2010 (Tanenbaum) at 59-61

Background

- OSI Reference Model



Ex. 2010 (Tanenbaum) at 62

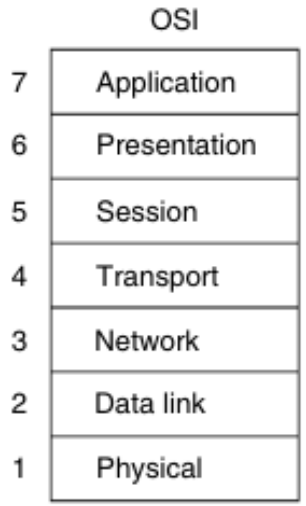
Network Layer:

- Controls operation of subnet, e.g. network addressing, routing paths
- Recipient network address is the final destination on the subnetwork, e.g. local router's network address
- Controls how packets are routed from network to network
  - E.g. builds routing tables for deciding where to forward packets
  - Handles routing between different networks, which may have different protocols
- Defines how to handle network congestion and QoS issues, e.g. prioritizing different traffic or choosing different routes

Ex. 2010 (Tanenbaum) at 59-61

Background

- OSI Reference Model



Ex. 2010 (Tanenbaum) at 62

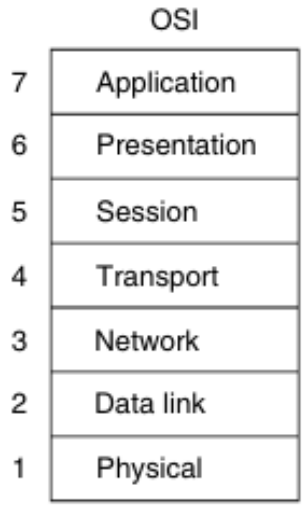
Data Link Layer:

- Ensures raw transmissions are free of transmission errors
- Splits data into data frames and transmits sequentially, confirms receipt
- For broadcast ***networks*** (distinct from the transport protocol), MAC sublayer controls access to a shared channel

Ex. 2010 (Tanenbaum) at 59-61

Background

- OSI Reference Model



Ex. 2010 (Tanenbaum) at 62

Physical Layer:

- Transmits raw bits over a communication channel
- Decides what electrical signals represent 1s and 0s
- Performs error correction
- Decides how connections are established

Ex. 2010 (Tanenbaum) at 59-61

Background

- TCP/IP Reference Model

> "When satellite and radio networks were added later, the existing protocols had trouble interworking with them, so a new reference architecture was needed. Thus, from nearly the beginning, the ability to connect multiple networks in a seamless way was one of the major design goals."

Ex. 2010 (Tanenbaum) at 61

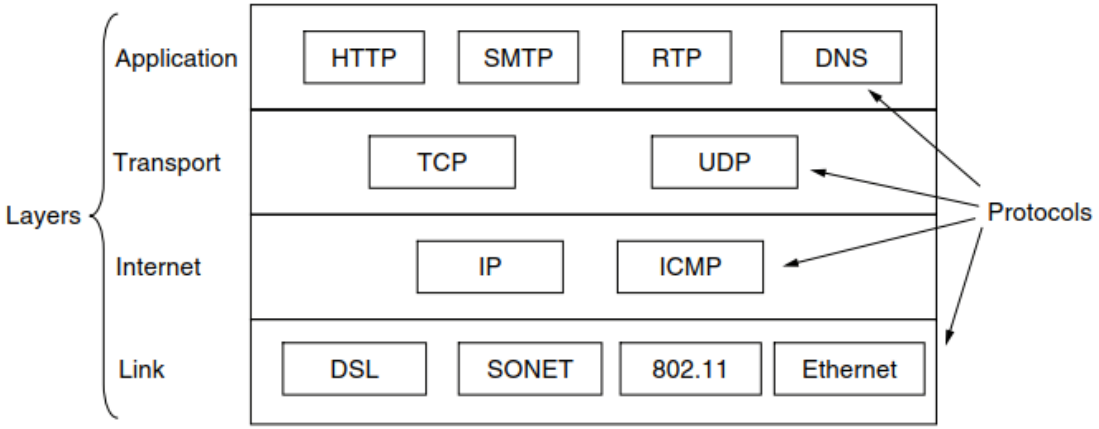


Figure 1-22. The TCP/IP model with some protocols we will study.

Ex. 2010 (Tanenbaum) at 64

Application Layer:

- High-level protocols commonly needed by users, like HTTP
- Applications define session and presentation functions if needed, such as how data is encoded, what data structures it uses, how sessions are maintained, etc.

Ex. 2010 (Tanenbaum) at 62-64

Background

- TCP/IP Reference Model

> "When satellite and radio networks were added later, the existing protocols had trouble interworking with them, so a new reference architecture was needed. Thus, from nearly the beginning, the ability to connect multiple networks in a seamless way was one of the major design goals."

Ex. 2010 (Tanenbaum) at 61

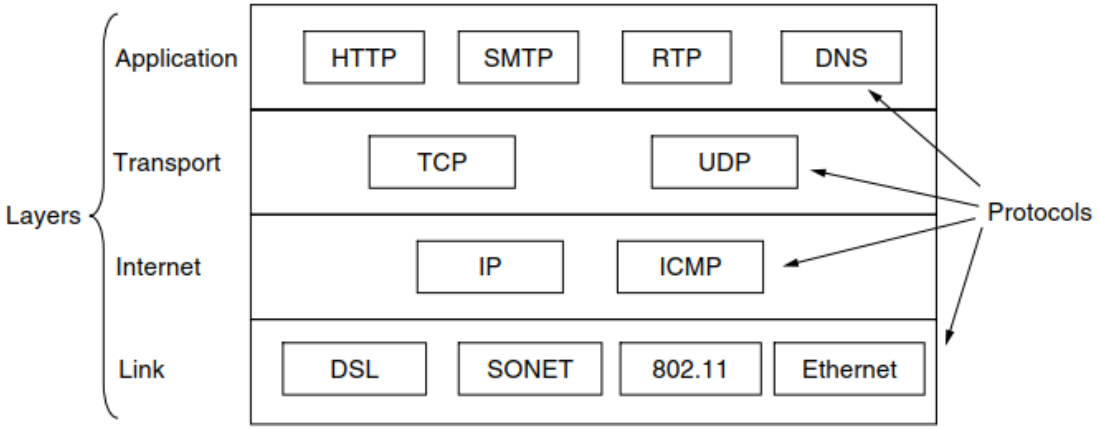


Figure 1-22. The TCP/IP model with some protocols we will study.

Ex. 2010 (Tanenbaum) at 64

Transport Layer:

- Defines how host and destination machines communicate
- Splits up data into packets
- TCP ensures packets are delivered without error and in order
- UDP broadcasts packets and is faster but does not ensure sequencing or guarantee delivery

Ex. 2010 (Tanenbaum) at 62-64

Background

- TCP/IP Reference Model

> "When satellite and radio networks were added later, the existing protocols had trouble interworking with them, so a new reference architecture was needed. Thus, from nearly the beginning, the ability to connect multiple networks in a seamless way was one of the major design goals."

Ex. 2010 (Tanenbaum) at 61

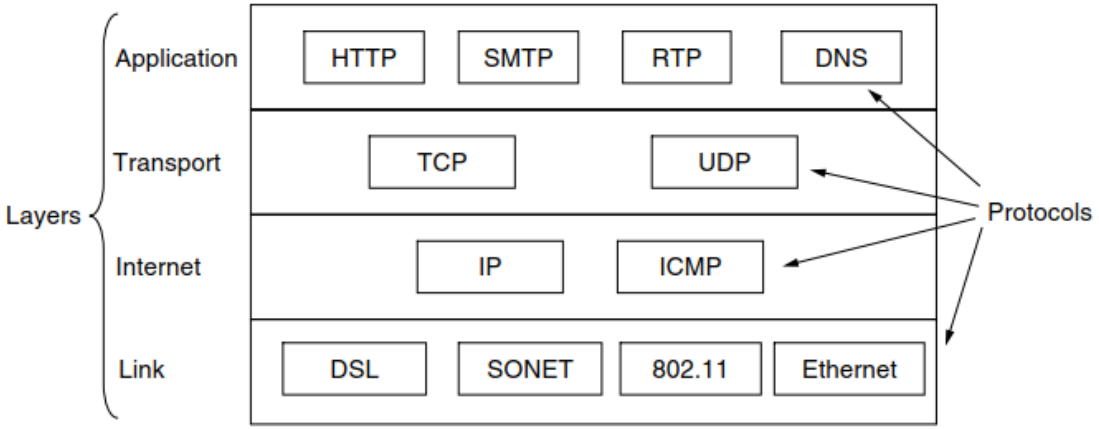


Figure 1-22. The TCP/IP model with some protocols we will study.

Ex. 2010 (Tanenbaum) at 64

Internet Layer:

- Uses IP addresses for routing across multiple networks
  - IP address defines the subnetwork
- Sets the recipient as the next gateway on the network
- Performs packet routing using routing tables
- Controls network congestion, e.g. dropping packets, DSCP field that labels priority

Ex. 2010 (Tanenbaum) at 62-64

Background

- TCP/IP Reference Model

> "When satellite and radio networks were added later, the existing protocols had trouble interworking with them, so a new reference architecture was needed. Thus, from nearly the beginning, the ability to connect multiple networks in a seamless way was one of the major design goals."

Ex. 2010 (Tanenbaum) at 61

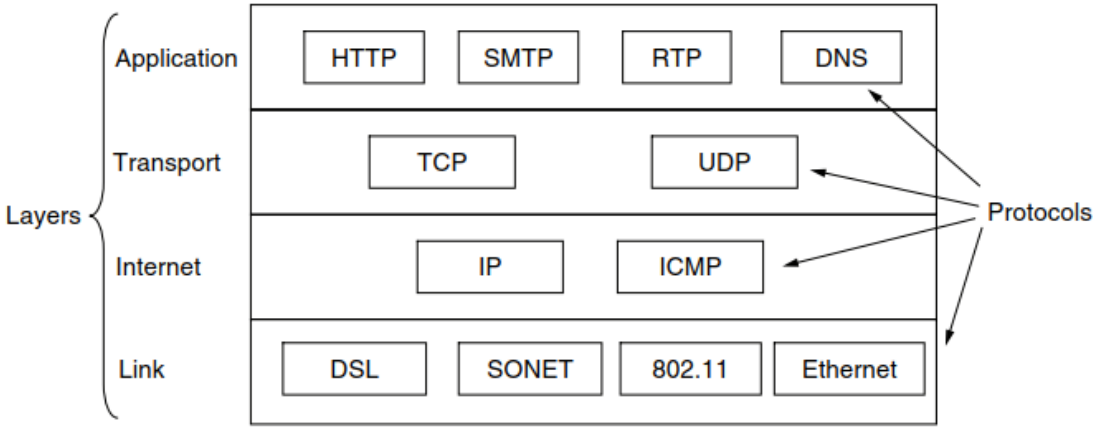


Figure 1-22. The TCP/IP model with some protocols we will study.

Ex. 2010 (Tanenbaum) at 64

Link Layer:

- Interface between hosts and transmission links
- Describes what lower links (e.g. Ethernet) must do to meet the needs of the Internet layer

Ex. 2010 (Tanenbaum) at 62-64

Background

- Adjacent layers communicate via interfaces

"Between each pair of adjacent layers is an **interface**."

Ex. 2010 (Tanenbaum) at 46

"A *service* is a set of primitives (operations) that a layer provides to the layer above it. The service defines what operations the layer is prepared to perform on behalf of its users, but it says nothing at all about how these operations are implemented. A service relates to an interface between two layers, with the lower layer being the service provider and the upper layer being the service user."

Ex. 2010 (Tanenbaum) at 56

- The interfaces are **not** defined by any model or standard

"Neither the details of the implementation nor the specification of the interfaces is part of the architecture because these are hidden away inside the machines and not visible from the outside. It is not even necessary that the interfaces on all machines in a network be the same, provided that each machine can correctly use all the protocols."

Ex. 2010 (Tanenbaum) at 47

Background

- Protocols define how layers on different machines communicate with each other
- Protocols are **not** interfaces

"To repeat this crucial point, services relate to the interfaces between layers, as illustrated in Fig. 1-19. In contrast, protocols relate to the packets sent between peer entities on different machines. It is very important not to confuse the two concepts."

Ex. 2010 (Tanenbaum) at 56

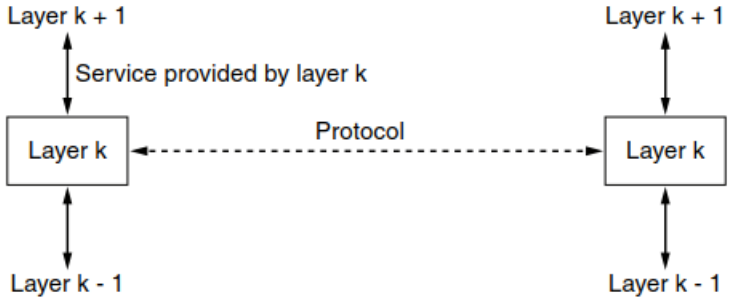


Figure 1-19. The relationship between a service and a protocol.

Ex. 2010 (Tanenbaum) at 57

Background

- Each layer's protocol defines the **header** used to communicate with another machine

"Layer 2 adds to each piece not only a header but also a trailer, and gives the resulting unit to layer 1 for physical transmission. At the receiving machine the message moves upward, from layer to layer, with headers being stripped off as it progresses. None of the headers for layers below n are passed up to layer n."

Ex. 2010 (Tanenbaum) at 48

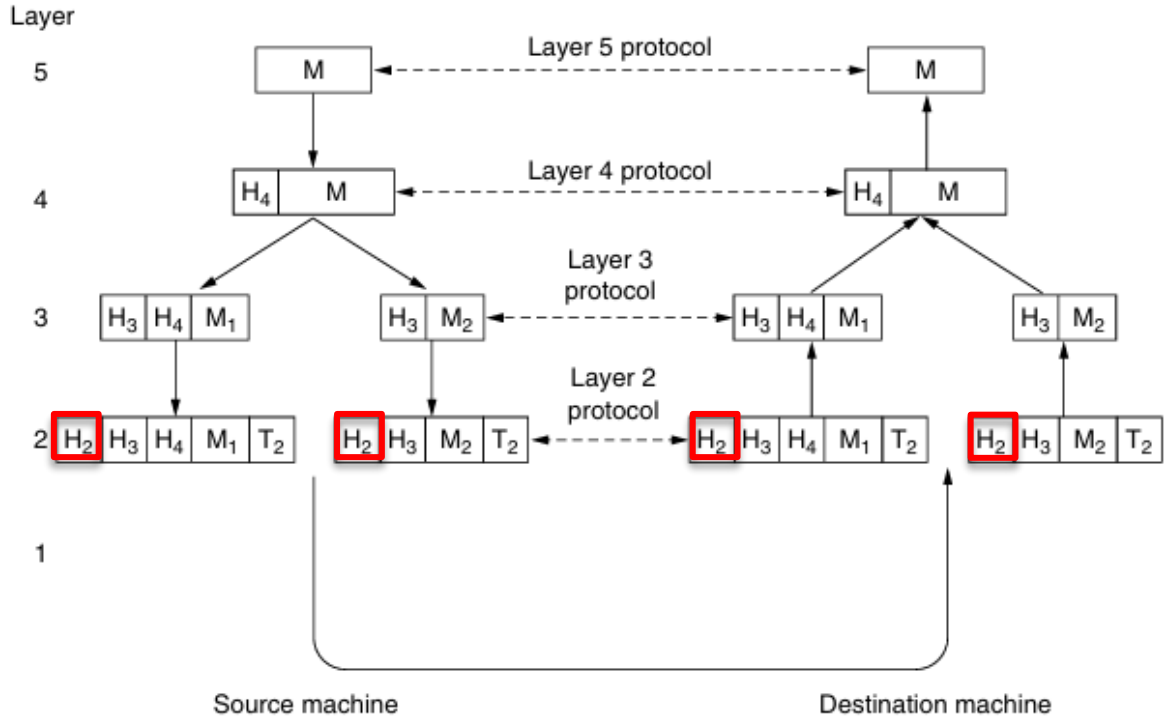


Figure 1-15. Example information flow supporting virtual communication in layer 5.

Ex. 2010 (Tanenbaum) at 49

Background

- MAC addresses are defined by the **IEEE 802 protocol** used for the data link layer

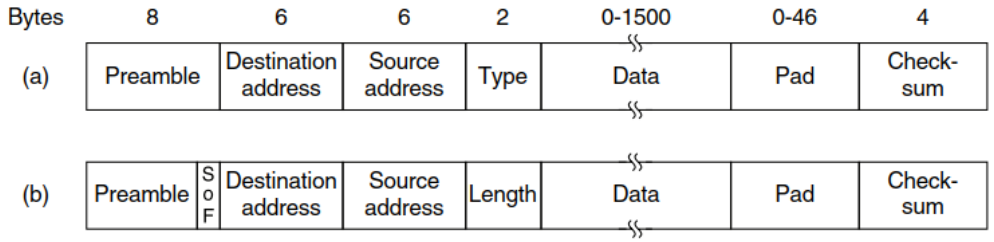


Figure 4-14. Frame formats. (a) Ethernet (DIX). (b) IEEE 802.3.

Ex. 2010 (Tanenbaum) at 234

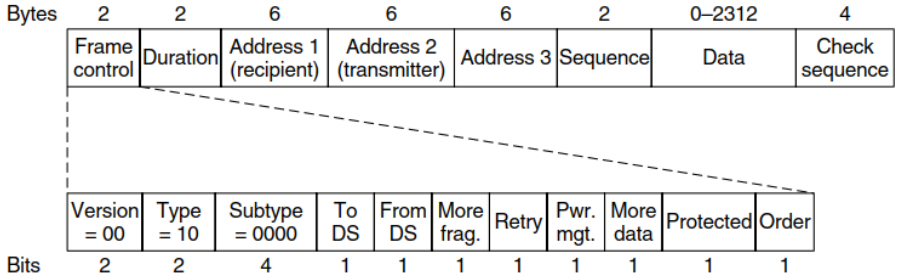


Figure 4-29. Format of the 802.11 data frame.

Ex. 2010 (Tanenbaum) at 262

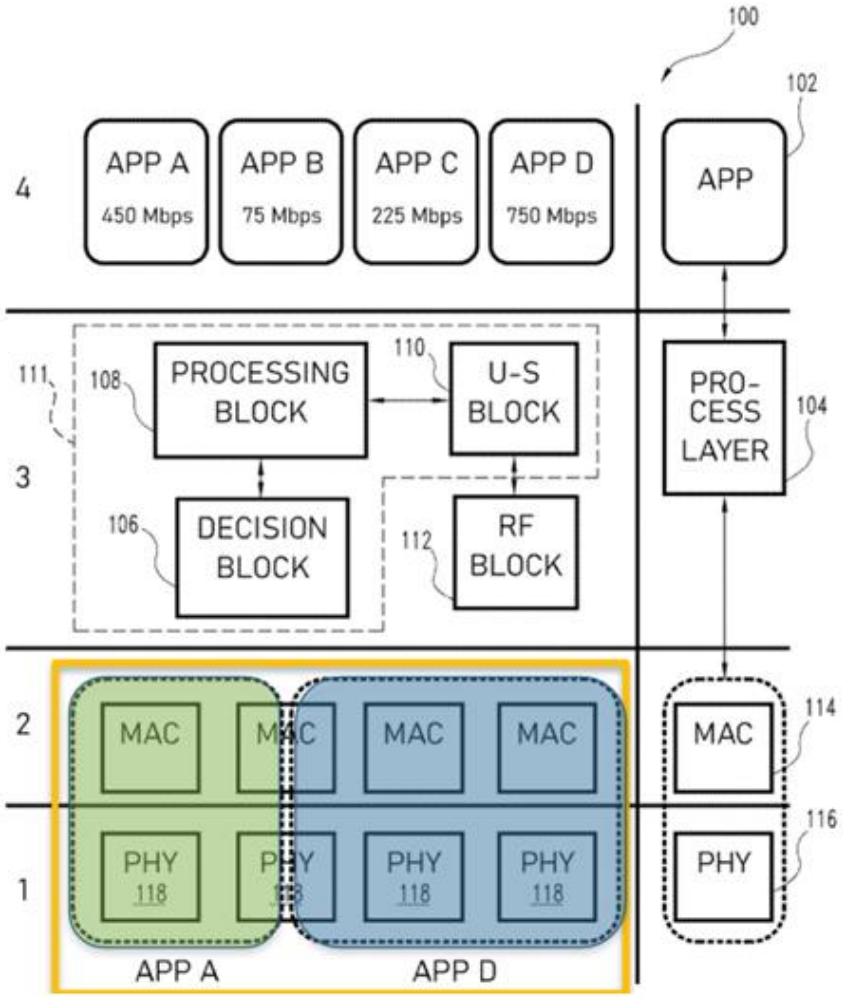
- MAC addresses are used to **identify the recipient machine**

> "Since there are many computers on the network, every layer needs a mechanism for identifying the senders and receivers that are involved in a particular message. This mechanism is called addressing or naming, in the low and high layers, respectively."

Ex. 2010 (Tanenbaum) at 50

Overview of Patents

Overview of Patents

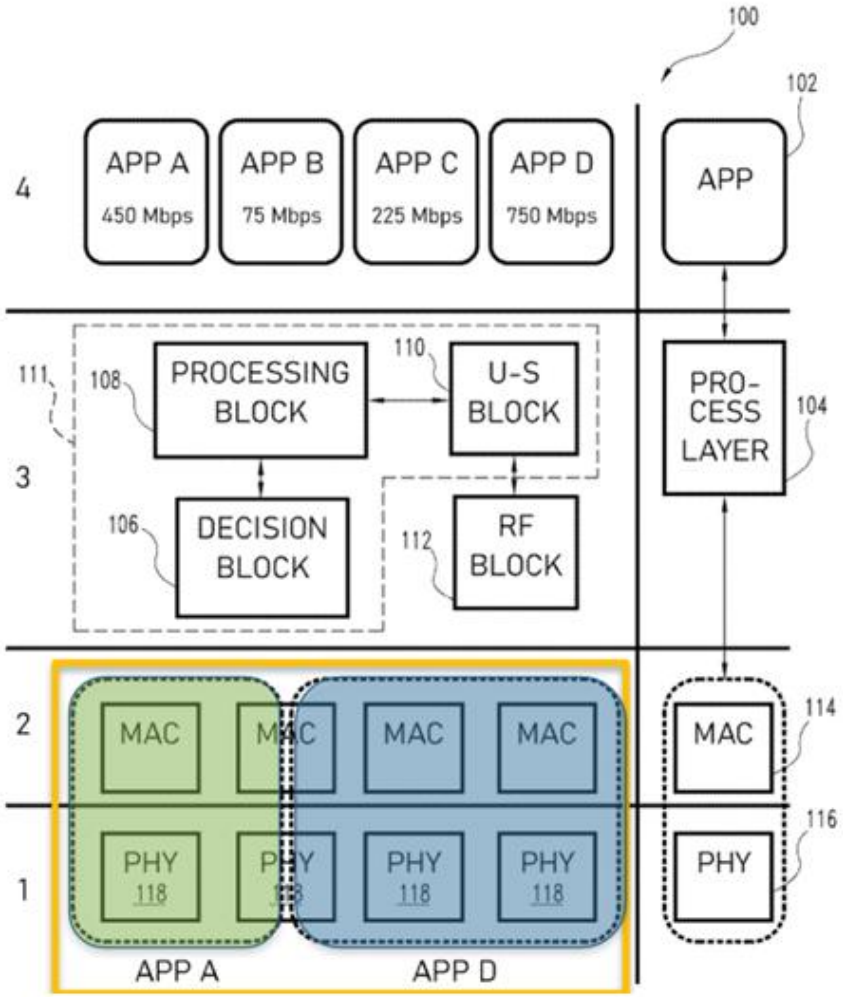


Ex. 1001 (564 patent) at Fig. 1 (annotated by PO)

"A processing layer evaluates the wireless bandwidth requirement and the first and second bandwidth availabilities of the wireless transceiver resources. The processing layer includes a bandwidth allocator to allocate at least a portion of each of the first and second actual bandwidths to virtual MAC and virtual PHY layers, and to satisfy the application layer wireless bandwidth requirement."

Ex. 1001 (564 patent) at 2:48-55; POR 8

Overview of Patents



Ex. 1001 (564 patent) at Fig. 1 (annotated by PO)

"Using the same example shown in FIG. 1 , and assuming that all of the PHY transceivers are available, each PHY transceiver 118 is capable of providing a transmit/receive bandwidth of 300 Mbps. Grouping the entire bandwidth of one transceiver with half the bandwidth of a second satisfies the bandwidth demand for Application A. In a similar manner, allocating the bandwidths of two transceivers, and half the bandwidth of a third transceiver satisfies the bandwidth demand for Application D. The allocating is managed by defining the virtual MAC/PHY layers 111 and 112 with the allocated resources, at 208."

Ex. 1001 (564 patent) at 2:48-55; POR 8

Overview of Patents

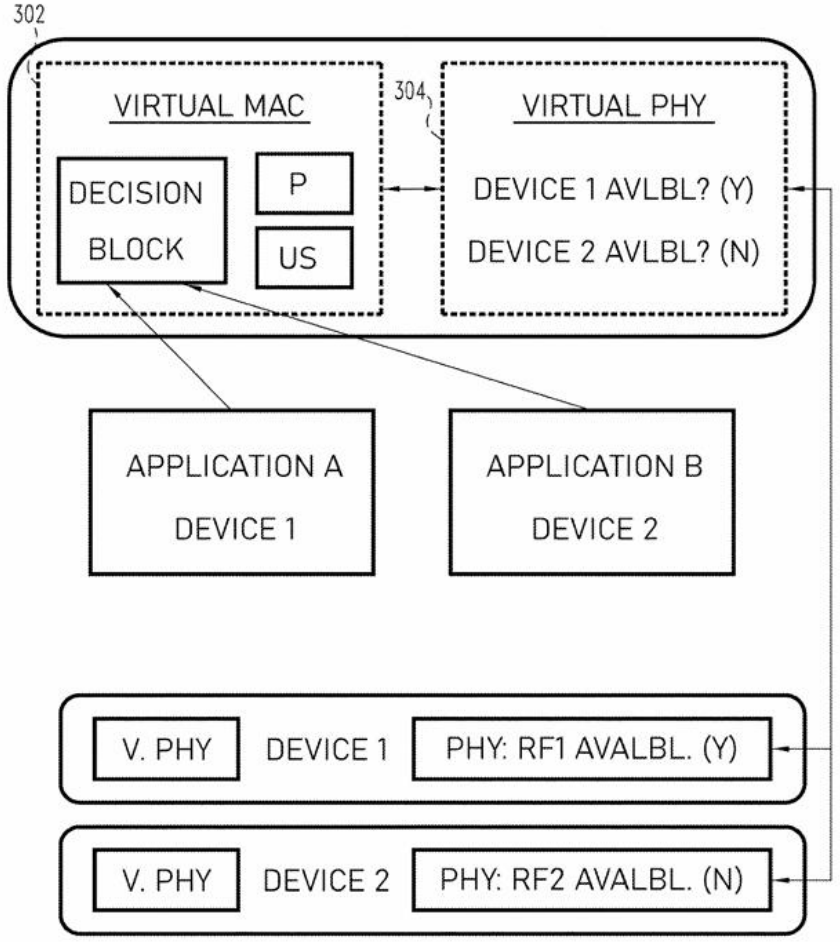


Fig. 4

Ex. 1001 (564 patent) at Fig. 4

"Referring now to FIG. 4 , defining the virtual MAC and PHY layers 302 and 304 involves an evaluation of available transceiver resources to meet peak bandwidth demands of applications running in the application layer. One or more applications, such as "Application A" and "Application B", may be initially supported with transceiver resources "Device 1" and "Device 2" through an initialization or training process at startup. The virtual MAC 302 interfaces with the virtual PHY 304 to determine device availability. This further involves a determination at the PHY layer as to the actual availability of the initially assigned transceiver resources. Should a given resource be unavailable, such as through insufficient bandwidth or having an existing assignment, a replacement resource may be identified and assigned."

Ex. 1001 (564 patent) at 4:61-5:8; POR at 8

Summary of Prior Art

Summary of Prior Art: Chincholi (Ex. 1005)

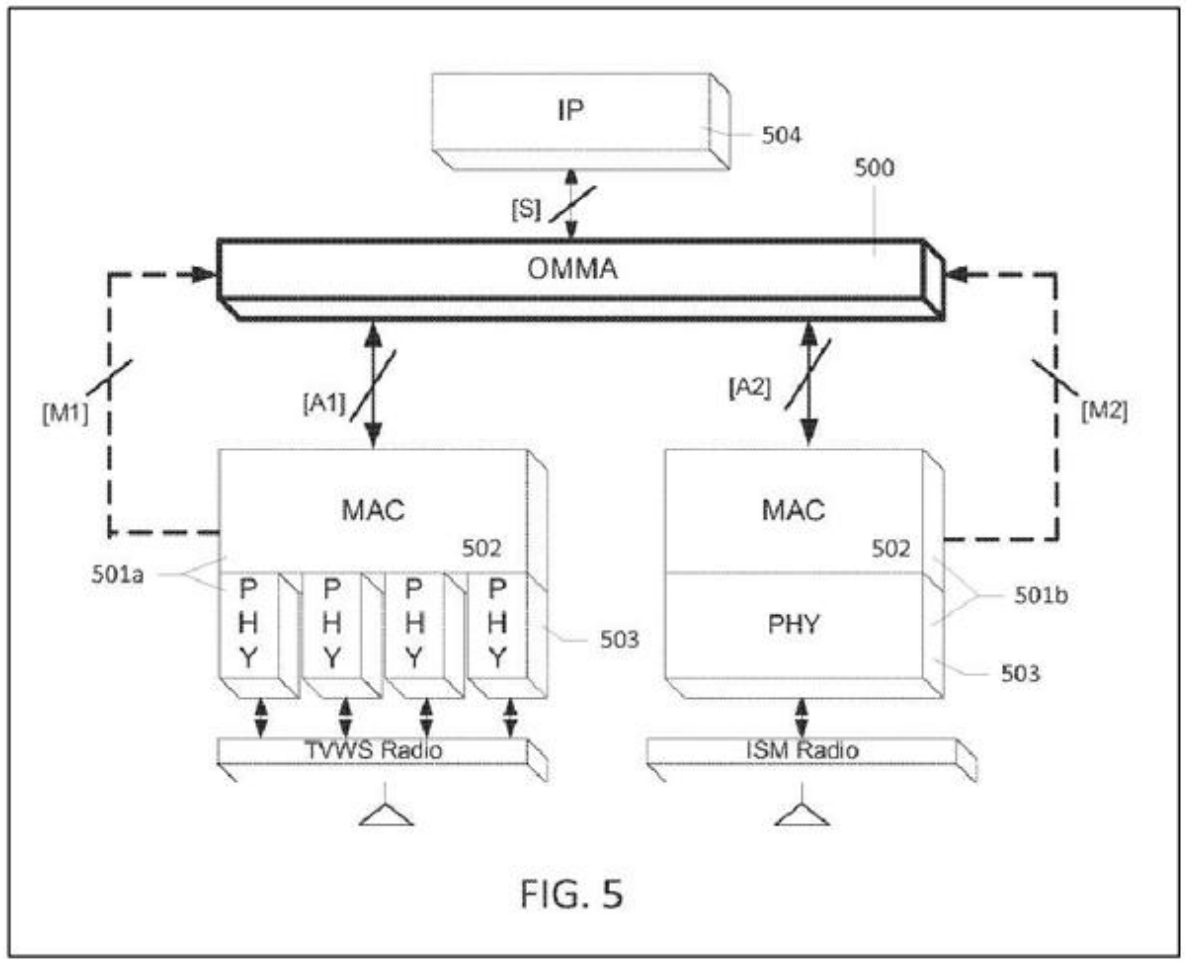


FIG. 5

Ex. 1005 (Chincholi) at Fig. 5

"A mechanism to aggregate two or more RATs operating independently on two or more bands to enhance the total IP throughput of the link may be described herein. For example, a single thin software layer (e.g., an opportunistic multi-medium access control (MAC) aggregation (OMMA) layer) may be described herein. For example, the single thin software layer may reside above the medium access control (MAC) layers of the protocol stacks but below the IP layer. For example, the single thin software layer may enable one RAT to operate over industrial scientific medical (ISM) and another RAT to operate over a TVWS band for the same IP flow. This may allow for enhanced throughput and reduced latency for a single IP flow."

Ex. 1005 (Chincholi) at [0120]; Pet. 7

Summary of Prior Art: Chincholi (Ex. 1005)

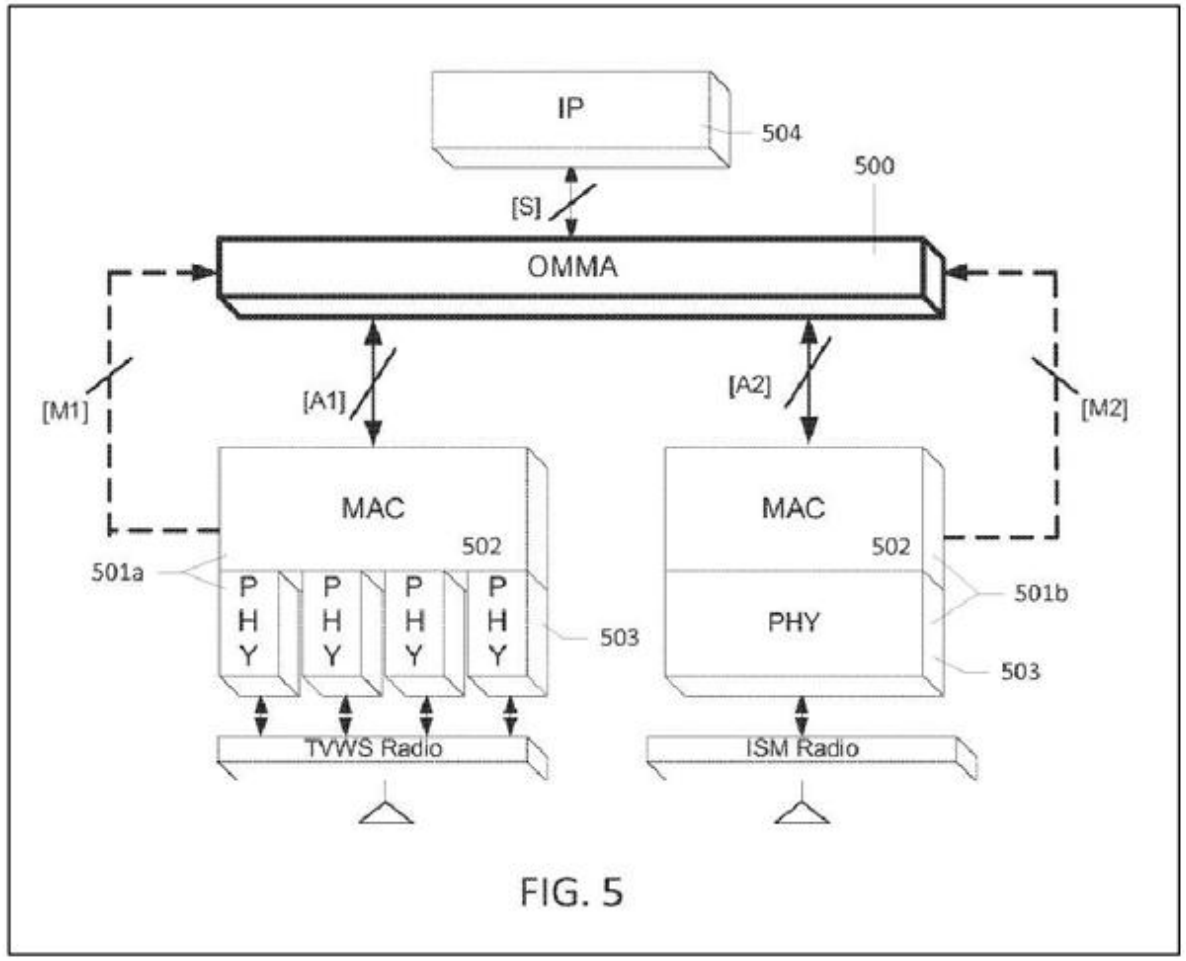


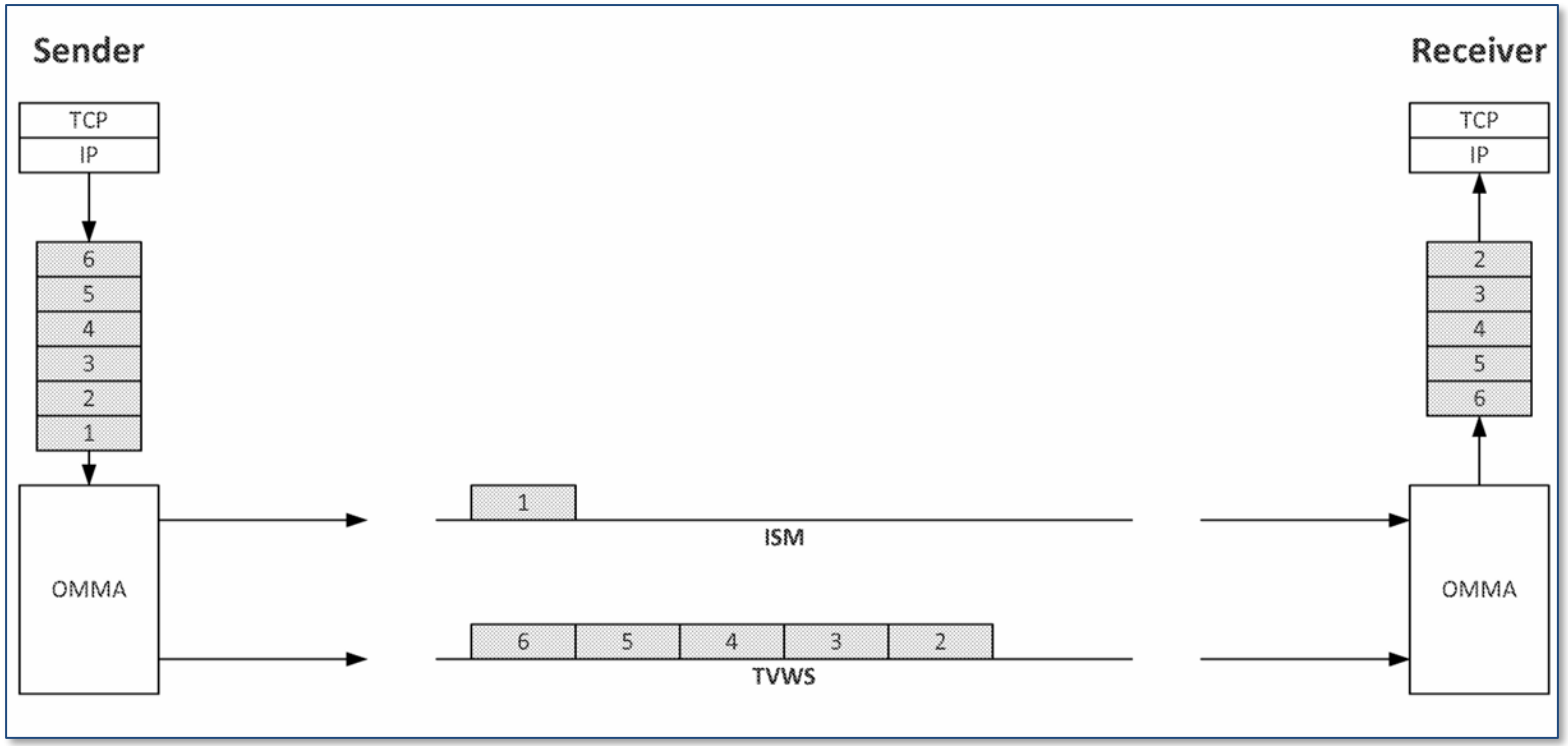
FIG. 5

Ex. 1005 (Chincholi) at Fig. 5

"The OMMA layer 600 may comprise one or more of the following: a traffic shaping module 601, a MAC resource reservation module 602, and an internet protocol (IP) quality of service (QoS) scheduler 603. The traffic shaping module 601 may responsible for determining the way packets are routed across RATs. For example, the traffic shaping module may determine the way a packet is routed using policy based routing or feedback based routing."

Ex. 1005 (Chincholi) at [0139]; Pet. 27

Summary of Prior Art: Chincholi (Ex. 1005)



Ex. 1005 (Chincholi) at Fig. 19; Reply 6

"For example, it may be assumed that the sender has six packets to transmit to the receiver. The packets may reach the OMMA layer on the sender side, which may decide that the first packet is to be transmitted over 802.1 In while the remaining five packets are to be transmitted over the TVWS channels."

Ex. 1005 (Chincholi) at [0172]; Reply 6

Summary of Prior Art: Chincholi (Ex. 1005)

"When the receiving OMMA layer receives a packet it may remove the OMMA header and route the packet to the IP layer based on the information within the OMMA header. If the flow ID is set to zero, the packet may not be part of a TCP flow and may be pushed to the IP layer. If the flow ID is not set to zero, the receiving OMMA layer may compare the sequence number with the next expected sequence number for that specific flow. If it is the next expected packet, the OMMA layer may be forwarded to the IP layer. If it is not the next expected packet, the receiving OMMA layer may hold the packet and start a timer. Upon expiry of the timer, the packet may be forwarded to the IP layer. If other packets are received while the timer has not expired, the OMMA layer may perform the same logic, forwarding it to the IP layer if it is the next expected packet. As new packets are received, the packets that are being held, as a result of not being the next expected packet, may be re-evaluated to see if they are now the next expected packet. If they are the next expected packet, the OMMA layer may forward the packet to the IP layer without waiting for the timer to expire."

Ex. 1005 (Chincholi) at [0172]; Reply 6

“virtual MAC interface” (All Patents)

Chincholi discloses a "virtual MAC interface"

Agreed Construction
"virtual MAC interface"
"a software- or logical-based interface that is separately addressable from the recited actual MAC interfaces and that obscures the recited actual MAC interfaces from higher protocol stack layers"

- **PO:**
  - Chincholi's OMMA is not "separately addressable"
  - Chincholi's OMMA does not "obscure" the actual MAC layers
  - Chincholi's OMMA is not a sublayer on layer 2
  - Chincholi's OMMA is not "virtual" and does not perform functions of "virtual MAC interface"

- PO is ***incorrect***:
  - Chincholi expressly discloses that other devices directly address the OMMA Scheduler
  - Chincholi expressly discloses that the actual MAC layers are obscured from higher layers
  - District Court held no requirement that the "virtual MAC interface" be on layer 2
  - Chincholi's OMMA includes the same claimed functions as the "virtual MAC interface"

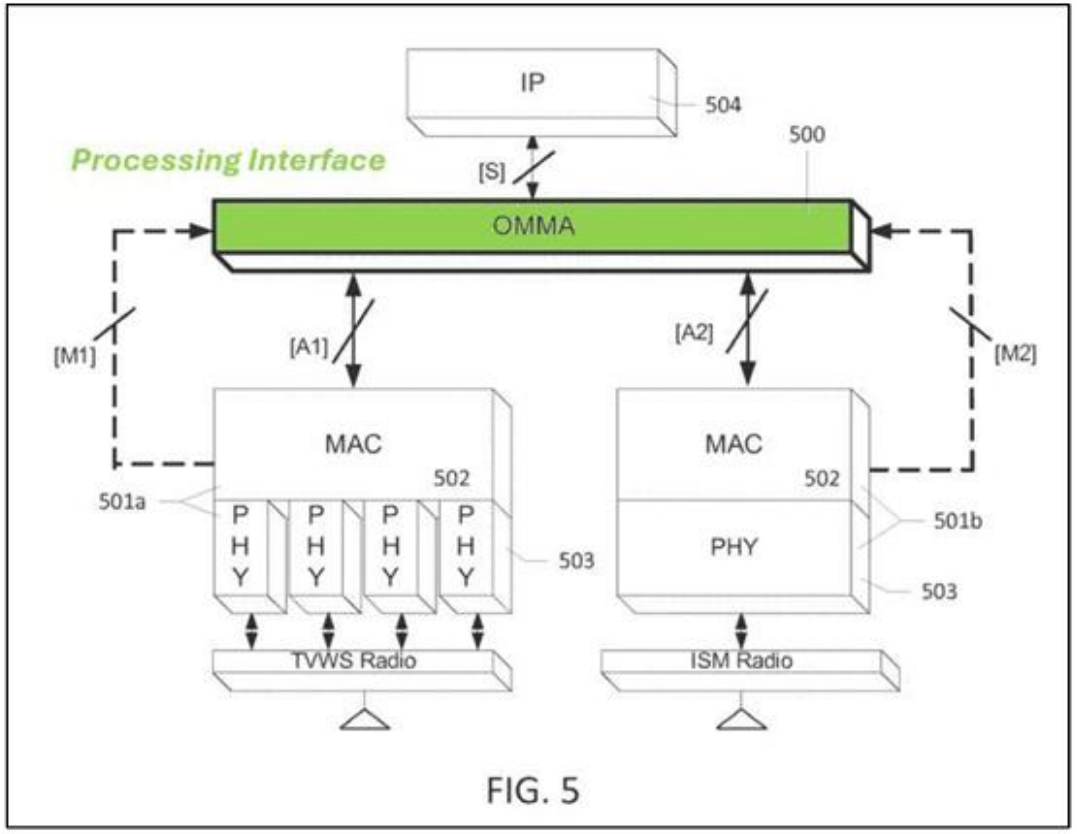
Chincholi discloses a “virtual MAC interface”: “separately addressable”

- **PO:** Chincholi’s OMMA is not “separately addressable” **POR 34-35, Surreply 8-9**
  - OMMA does not have its own “programmed or non-static address” for transferring data **POR 35**
  - OMMA is merely a conduit for passing information **POR 35**
  - OMMA does not intervene between actual MAC and higher protocol layers when transmitting data **Surreply 9**

- **Incorrect:**
  - OMMA Scheduler uses an address to transfer data to another device’s OMMA Scheduler **Reply 7**
  - Neither claims nor intrinsic evidence suggest the “virtual MAC interface” must have its own programmed address **Reply 8**
  - OMMA includes functionality that intervenes between higher and lower layers, deciding how to route packets **Reply 8**

Chincholi discloses a "virtual MAC interface": "separately addressable"

- **Chincholi's OMMA layer includes functionality that is "separately addressable"**



Ex. 1005 (Chincholi) at Fig. 5 (annotated)

"Table 1 may provide the interfaces between an OMMA layer (e.g., OMMA layer 500) and an IP layer (e.g., IP layer 504) and one or more RATs (e.g., RATs 501a, 501b), for example, as shown in FIG. 5."

Ex. 1005 (Chincholi) at ¶[0138]; Pet. 17-18

Table 1

Interface	Description
M1	Meta-data/link statistics from TVWS band protocol stack to thin layer
M2	Meta-data/link statistics from ISM band protocol stack to thin layer
A1	Incoming/Outgoing MAC MSDUs on TVWS band, and MAC resource reservation control signaling
A2	Incoming/Outgoing MAC MSDUs on ISM band, and MAC resource reservation control signaling
S	Incoming/Outgoing IP Packets

Chincholi discloses a "virtual MAC interface": "separately addressable"

- Chincholi's OMMA Scheduler is "separately addressable" by the OMMA of other devices:

"At the WTRU side, the OMMA Scheduler 3180 (e.g. , RAT Update Sender) may query (e.g., periodically query) the RAT Availability Database 3170 for a RAT availability list of an associated NT, for example, via a STA_RAT_Capability_Query_A4 signal on interface A4 (e.g., as shown in FIG. 28). After receiving a response (e.g., STA_RAT_Capability_Response_A4) for the above request, the OMMA scheduler 3180 may generate a STA_RAT_Availability message, for example, with one or more of the following parameters, to be sent using over-the-air signaling:

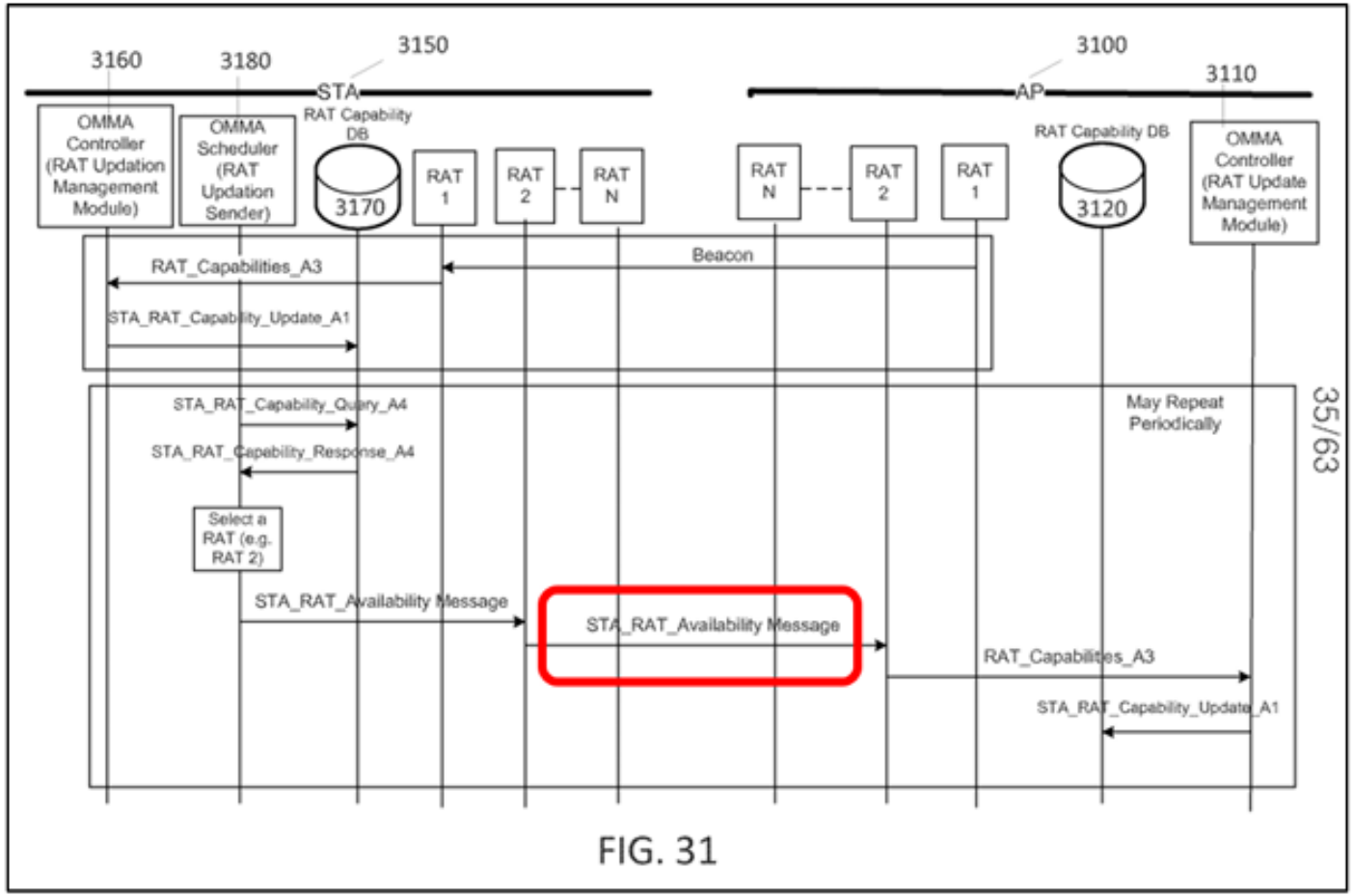
- STA_Addr: Self Address
- AP_Addr: Address of a NT (e.g., which it needs to send a message)
- RAT Ids: List of Ids of RATs (e.g., which are available) (e.g., [RAT_1, RAT_2])

The OMMA Scheduler 3180 (e.g., RAT Update Sender) at the WTRU 3150 may transmit RAT availability information to the NT 3100 using one of the operational RATs at that time. At the NT 3100, the RAT that receives the STA_RAT_Availability message may signal the OMMA Controller 3110 (e.g., RAT Update Management module), for example, via a RAT_Capablities_A3 on interface A3 (e.g., as shown in FIG. 28). The OMMA Controller 3110 (e.g., RAT Update Management module) may update information of RAT Availability in the RAT Capability Database 3120 for that WTRU …"

Ex. 1005 (Chincholi) at [0244]-[0245]; Reply 7

Chincholi discloses a "virtual MAC interface": "separately addressable"

- Chincholi's OMMA Scheduler is "separately addressable" by the OMMA of other devices:



Ex. 1005 (Chincholi) at Fig. 31 (annotated); Reply 7

"A POSITA would have recognized that Chincholi's OMMA Controller is separately addressable because the STA_RAT_Availability message is directed to OMMA functionality of the NT, and the OMMA Controller receives that information and updates the RAT Capability Database. A POSITA would have understood Chincholi's OMMA-directed signaling to the NT's OMMA Controller as demonstrating that the OMMA Controller is an addressable logical interface distinct from the actual MAC interfaces."

Ex. 1026 (Almeroth Supp. Decl.) at ¶42; Reply 7

Chincholi discloses a "virtual MAC interface": "separately addressable"

- Chincholi's OMMA Scheduler is "separately addressable" by the OMMA of other devices:

"Importantly, the STA_RAT_Availability message sent from the WTRU to the NT includes the following parameters: "STA_Addr," which is the self-address of the WTRU, "AP_Addr," which is the device-level address of the NT to which the message is sent, and "RAT_Ids," which is a list of the available RATs on the WTRU. EX1005 at [0244]. After the NT receives the STA_RAT_Availability message, it then signals the OMMA Controller to update information of the WTRU RAT availability in the RAT Capability Database. Id. at [0245]."

Ex. 1026 (Almeroth Supp. Decl.) at ¶40; Reply 7

"Thus, to summarize, multi-link WTRU stations in Chincholi send messages regarding their RAT availability to an associated NT. These messages are received by the RAT of the NT and directed to the OMMA Controller for purposes of updating a capability database. These messages are addressed to "AP_Addr," which is a device-level address for the NT that results in the availability message being directed to the OMMA Controller. The purpose of the message is to provide RAT-availability information to OMMA functionality so that the OMMA Controller can update the RAT Capability Database.

Ex. 1026 (Almeroth Supp. Decl.) at ¶41; Reply 7

Chincholi discloses a "virtual MAC interface": "separately addressable"

- Chincholi's OMMA Scheduler is "separately addressable" by the OMMA of other devices:

"A POSITA would have recognized that Chincholi's OMMA Controller is separately addressable because the STA_RAT_Availability message is directed to OMMA functionality of the NT, and the OMMA Controller receives that information and updates the RAT Capability Database. A POSITA would have understood Chincholi's OMMA-directed signaling to the NT's OMMA Controller as demonstrating that the OMMA Controller is an addressable logical interface distinct from the actual MAC interfaces.

Ex. 1026 (Almeroth Supp. Decl.) at ¶42; Reply 7

"The STA_RAT_Availability message includes addressing information for the OMMA of the destination NT/AP, including AP_Addr. EX1005 [0244] [0245]. A POSITA would have understood AP_Addr to be destination address information for the NT, separate from the actual MAC addresses of the NT's individual RATs. A POSITA would further understand that this address information is used to exchange signaling packets between WTRUs and the OMMA functionality of associated NTs over the wireless medium. Thus, the STA_RAT_Availability signaling confirms that the OMMA of the NT is separately addressable from the actual MAC interfaces.

Ex. 1026 (Almeroth Supp. Decl.) at ¶43; Reply 7

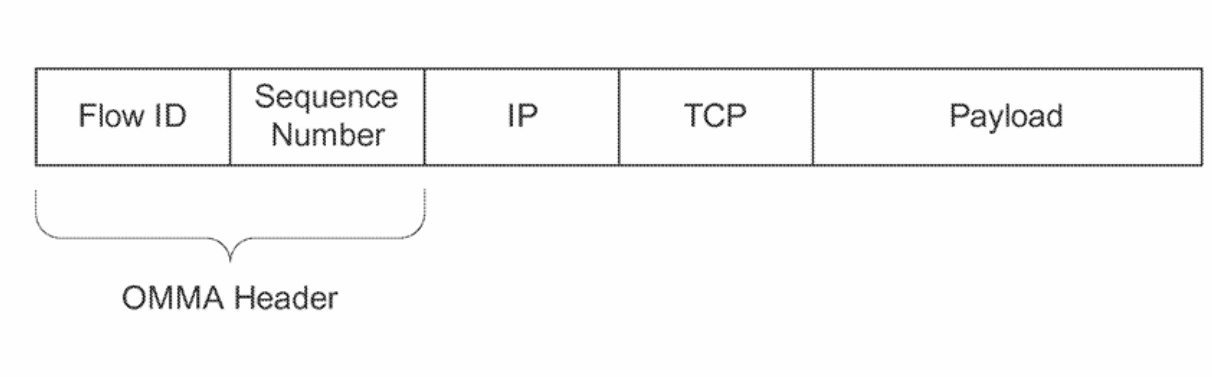
Chincholi discloses a "virtual MAC interface": "separately addressable"

- Chincholi's OMMA layer is "separately addressable" by the OMMA of other devices:

"A header may be added to the information, for example, in response to this addition of sequence numbers. The header may comprise a sequence number and/or a flow ID number, which may be used to restore the proper order to TCP flows within the receiving OMMA layer. …

When the receiving OMMA layer receives a packet it may remove the OMMA header and route the packet to the IP layer based on the information within the OMMA header."

Ex. 1005 (Chincholi) at ¶[0177]-[0178]; Reply 6,8



Ex. 1005 (Chincholi) at Fig. 22; Reply 6,8

Chincholi discloses a "virtual MAC interface": "separately addressable"

- **Surreply:** AP_Addr is not the OMMA's address, and OMMA only operates as a pass-through **POR 35; surreply 9**

- **Incorrect:**
  - AP_Addr is the address used to communicate with the OMMA Scheduler, and is separate from the actual MAC addresses, which is all that is required
  - OMMA Scheduler processes the RAT availability message, and does not pass it to upper layers

> "The OMMA Controller 3110 (e.g., RAT Update Management module) may update information of RAT Availability in the RAT Capability Database 3120 for that WTRU"

Ex. 1005 (Chincholi) at [0245]; Reply 7

Chincholi discloses a “virtual MAC interface”: “separately addressable”

- **Surreply:** AP_Addr is not the OMMA’s address, and OMMA only operates as a pass-through
  Surreply 8-9

> “The virtual MAC and PHY layers manage signals from one or more applications before sending the signals to the actual MAC and PHY layers.”

Ex. 1001 (564 patent) at 4:46-49; POR 34, Reply 8

Chincholi discloses a "virtual MAC interface": "separately addressable"

- **PO:** "separately addressable" means the "virtual MAC interface" must have its own "programmed or non-static" address that it uses for purposes of transferring data **POR 35**

> "Indeed, although a virtual MAC interface would have a programmed or non-static address, Chincholi's OMMA is not disclosed as being a separately addressable entity at all; it merely acts as a conduit to pass on packets received from different RATs (each with its own knowable actual MAC address), taking multiple inputs and sending them out as one output."

POR at 35

Chincholi discloses a "virtual MAC interface": "separately addressable"

- **PO:** "separately addressable" means the "virtual MAC interface" must have its own "programmed or non-static" address that it uses for purposes of transferring data POR 35
  - PO cites to **no intrinsic evidence** for a "programmed or non-static" address

- The challenged patents **only** describe the virtual MAC interface as processing data to/from adjacent layers:

> "FIG. 3 illustrates how, in one embodiment, elements associated with the process layer 104 can define a virtual MAC management layer 302 and a virtual PHY layer 304 to enable the sharing of multiple transceiver resources in a way sufficient to satisfy the bandwidth requirements of multiple applications running simultaneously. The virtual MAC and PHY layers manage signals from one or more applications before sending the signals to the actual MAC and PHY layers."

Ex. 1001 (564 patent) at 4:41-46; Pet. 25-26; Reply 8

Chincholi discloses a "virtual MAC interface": "separately addressable"

- **Surreply:** "separately addressable" means the "virtual MAC interface" must intervene between actual MAC and the higher protocol layers when sending data down Surreply 9

- OMMA has functionality which intervenes between higher protocol layers and the actual MAC:

"The traffic shaping module 601 may responsible for determining the way packets are routed across RATs. For example, the traffic shaping module may determine the way a packet is routed using policy based routing or feedback based routing."

Ex. 1005 (Chincholi) at [0139], Fig. 5 (annotated); Pet. 27

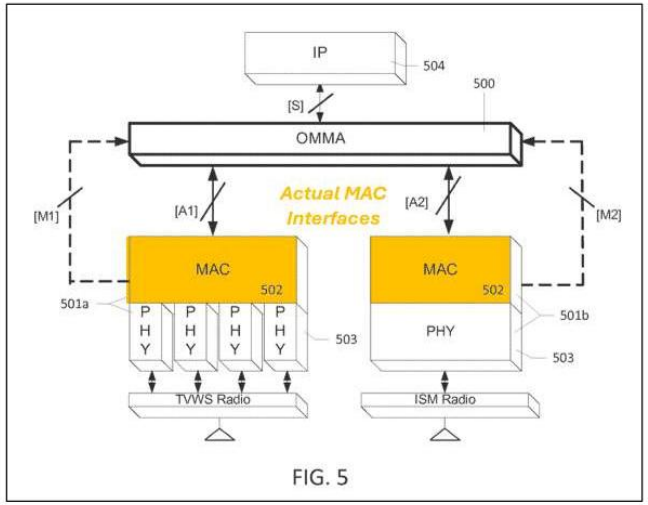


FIG. 5

- **'564 patent:**

"In a similar manner, allocating the bandwidths of two transceivers, and half the bandwidth of a third transceiver satisfies the bandwidth demand for Application D. The allocating is managed by defining the virtual MAC/PHY layers 111 and 112 with the allocated resources, at 208."

Ex. 1001 (564 patent) at 4:35-40; POR 70, Reply 8

Chincholi discloses a "virtual MAC interface": "obscure "

Agreed Construction
"virtual MAC interface"
"a software- or logical-based interface that is separately addressable from the recited actual MAC interfaces and that obscures the recited actual MAC interfaces from higher protocol stack layers"

- **PO:** Chincholi's OMMA is does not "obscure the actual MAC interfaces"
  - OMMA is merely forwards packets **POR 35, Surreply 10**
  - OMMA passes the actual MAC address to the IP layer **POR 33-35**
  - OMMA resides on layer 3, patent requires it be on layer 2 **POR 35, Surreply 9-10**
  - OMMA does not direct the RATs, as they operate independently of the OMMA **POR 37**
  - OMMA does not obscure the existence of the ***interface*** of the actual MAC interfaces **Surreply 10**

- **Incorrect:**
  - OMMA has functionality that decides how to distribute packets among the RATs
  - OMMA does not pass actual MAC headers or addresses
  - OMMA's components can reside on layer 2, and patent does not require virtual MAC to be on layer 2
  - The RATs operate independently of each other, not independently of the OMMA
  - OMMA is the only interface visible to higher layers, and so obscures the actual MAC interfaces

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- Chincholi's OMMA has functionality that obscures the MAC interface:
  - All traffic from the IP layer goes to the OMMA, and the OMMA's components decide which RATs to use

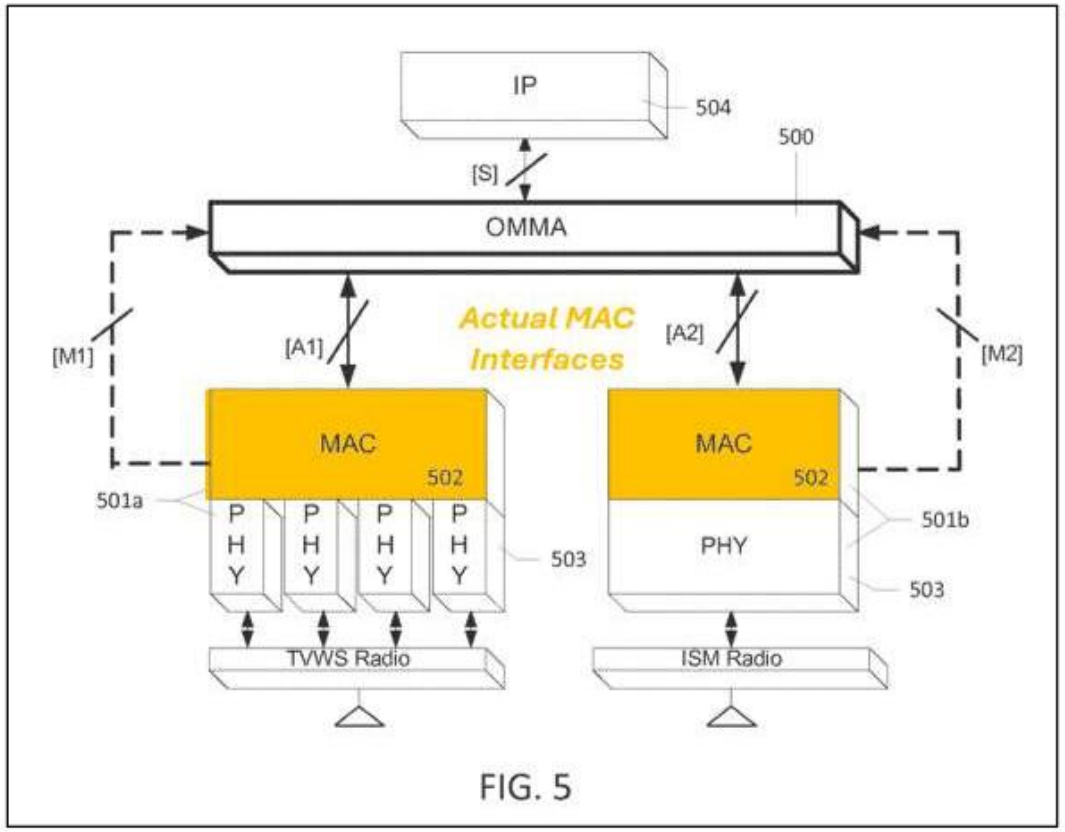


FIG. 5

Ex. 1005 (Chincholi) at Fig. 5

"The traffic shaping module 601 may responsible for determining the way packets are routed across RATs. For example, the traffic shaping module may determine the way a packet is routed using policy based routing or feedback based routing."

Ex. 1005 (Chincholi) at [0139]; Pet. 27

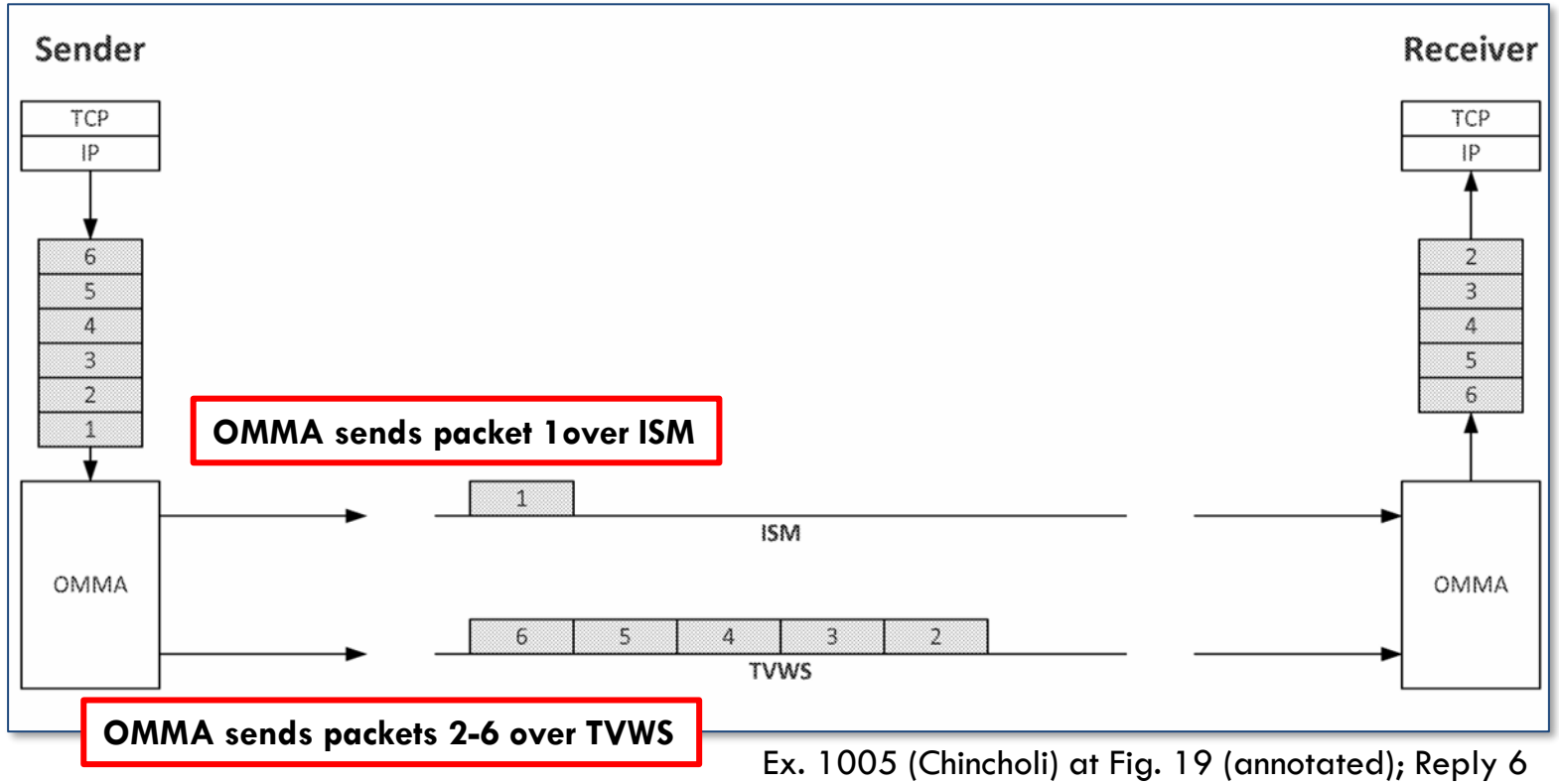
"A POSITA would have recognized that this 'virtualizes' a MAC interface because the OMMA would effectively appear to the IP layer as a single interface for exchanging packets that are ultimately sent or received by the actual MAC-PHY pairs."

Ex. 1002 (Almeroth Decl.) at ¶102; Pet. 26

- In Chincholi, IP layer ***never*** communicates with the actual MAC layers **Pet. 26, Reply 6**

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- OMMA has functionality which obscures: the OMMA components decide how to route IP packets



Ex. 1005 (Chincholi) at Fig. 19 (annotated); Reply 6

"For example, it may be assumed that the sender has six packets to transmit to the receiver. The packets may reach the OMMA layer on the sender side, which may decide that the first packet is to be transmitted over 802.1 In while the remaining five packets are to be transmitted over the TVWS channels."

Ex. 1005 (Chincholi) at [0172]; Reply 6

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- '564 Patent:

"It does not mean that [Chincholi's] actual MAC addresses are obscured; rather, they are apparent to the OMMA and to layers above the OMMA. Id. In contrast, in the '564 patent, packets are addressed using the virtual MAC address; upper layers do not see the actual MAC addresses."

POR at 34

"The virtual MAC and PHY layers manage signals from one or more applications before sending the signals to the actual MAC and PHY layers."

Ex. 1001 (564 patent) at 4:46-49; POR at 34

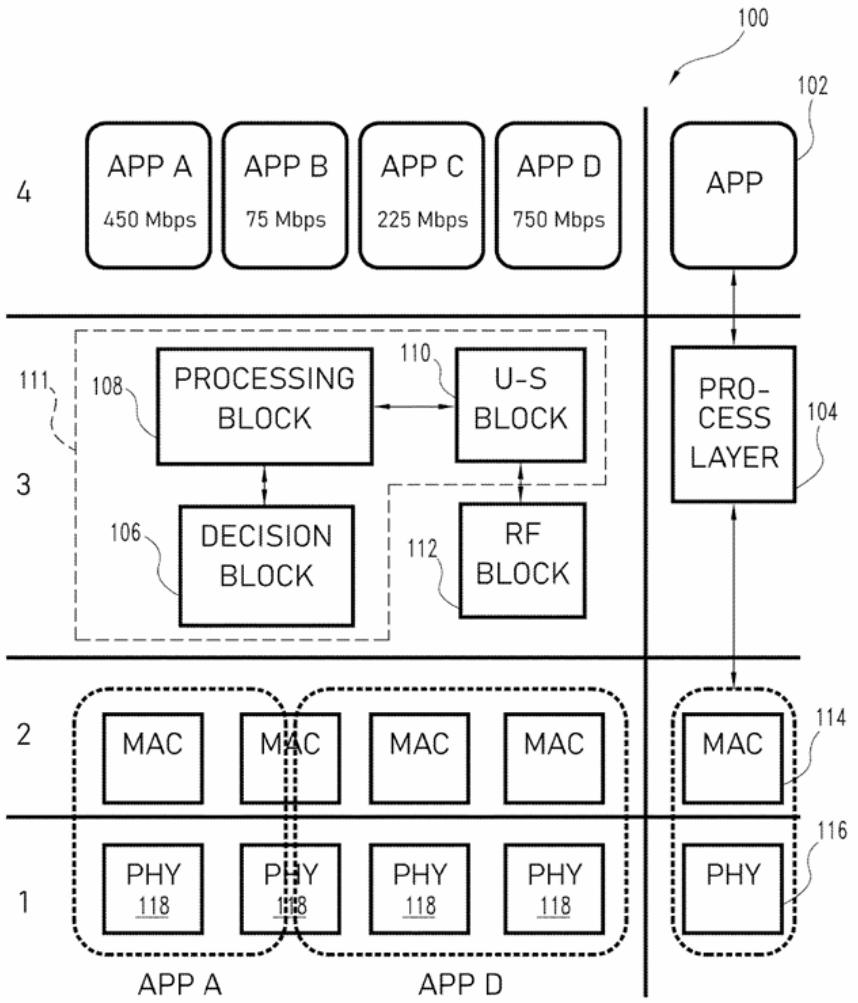


Fig. 1

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- Chincholi's OMMA has functionality which obscures the actual MAC interfaces because the OMMA decides to hold incoming packets if they are out of order:

"When the receiving OMMA layer receives a packet it may remove the OMMA header and route the packet to the IP layer based on the information within the OMMA header. If the flow ID is set to zero, the packet may not be part of a TCP flow and may be pushed to the IP layer. If the flow ID is not set to zero, the receiving OMMA layer may compare the sequence number with the next expected sequence number for that specific flow. If it is the next expected packet, the OMMA layer may be forwarded to the IP layer. If it is not the next expected packet, the receiving OMMA layer may hold the packet and start a timer. Upon expiry of the timer, the packet may be forwarded to the IP layer. If other packets are received while the timer has not expired, the OMMA layer may perform the same logic, forwarding it to the IP layer if it is the next expected packet. As new packets are received, the packets that are being held, as a result of not being the next expected packet, may be re-evaluated to see if they are now the next expected packet. If they are the next expected packet, the OMMA layer may forward the packet to the IP layer without waiting for the timer to expire."

Ex. 1005 (Chincholi) at [0172]; Reply 6, 8

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- Chincholi's OMMA has functionality that obscures the actual MAC interfaces because MAC headers are removed before sending to upper layers:

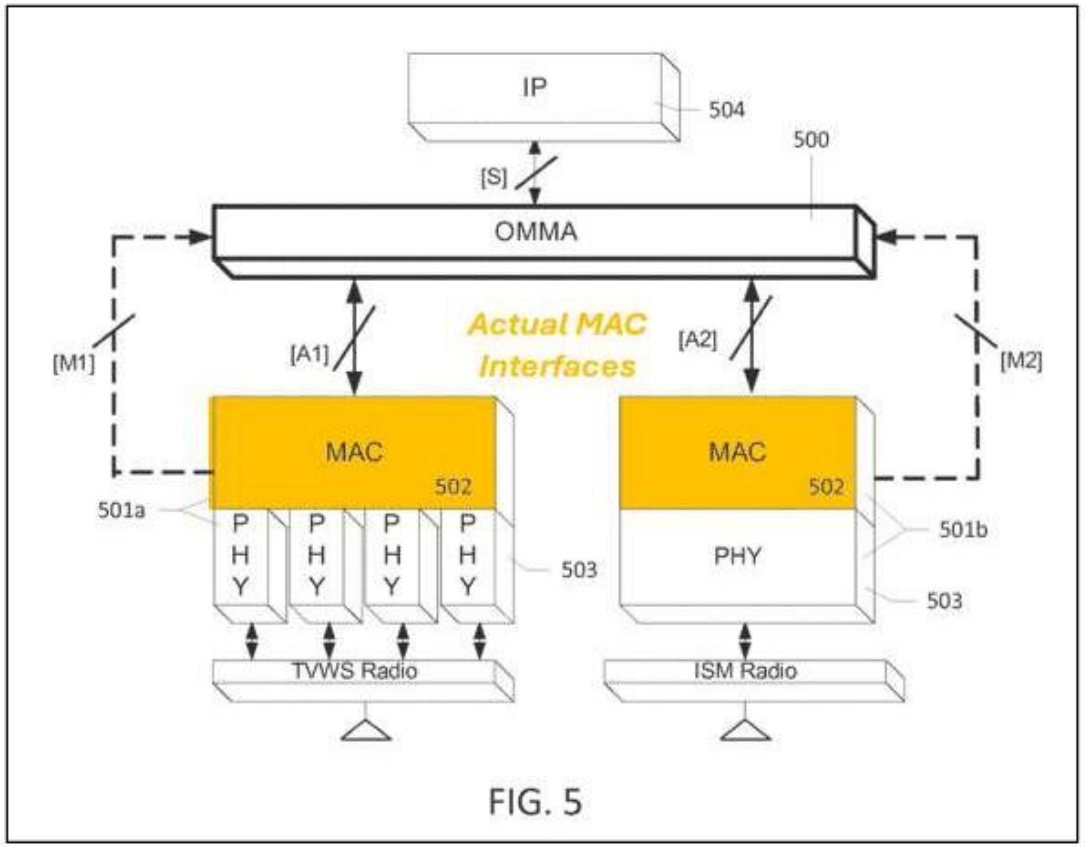


FIG. 5

Table 1

Interface	Description
M1	Meta-data/link statistics from TVWS band protocol stack to thin layer
M2	Meta-data/link statistics from ISM band protocol stack to thin layer
A1	Incoming/Outgoing MAC MSDUs on TVWS band, and MAC resource reservation control signaling
A2	Incoming/Outgoing MAC MSDUs on ISM band, and MAC resource reservation control signaling
S	Incoming/Outgoing IP Packets

Ex. 1005 (Chincholi) at [0138]; Reply 6

"In the incoming direction, the 802.11 MAC sublayer would perform a de-encapsulation process in which the MAC header would be removed from the MPDU, leaving only the MSDU. The MSDU would then be passed to higher layers."

Ex. 1026 (Almeroth Supp. Decl.) at ¶47; Reply 6

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- The actual MAC layers add/remove all MAC layer information

"In a typical 802.11 implementation at the time of Chincholi, the MAC sublayer would perform the function of encapsulating or "wrapping" an outgoing MSDU into a MAC Protocol Data Unit ("MPDU"). This process would involve the MAC sublayer adding a MAC header to the MSDU. The MAC header generally comprised four MAC address fields: (1) receiver MAC address ("RA"); (2) transmitter MAC address ("TA"); (3) destination address ("DA"); and (4) source address ("SA"). This MPDU, or "wireless frame," would then be passed to the physical layer for further preparation prior to being sent on the wireless channel. Thus, a POSITA would have understood that the MAC layer receives MSDUs containing higher-layer data payloads and wraps those payloads with MAC headers to generate MPDUs for transmission."

"In the incoming direction, the 802.11 MAC sublayer would perform a de-encapsulation process in which the MAC header would be removed from the MPDU, leaving only the MSDU. The MSDU would then be passed to higher layers."

"Because Chincholi describes the OMMA handling incoming and outgoing "MSDUs," a POSITA would have understood that the data packets processed by the OMMA would lack the MAC headers containing the actual MAC addresses."

Ex. 1026 (Almeroth Supp. Decl.) at ¶46-48; Reply 6

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** Chincholi's OMMA passes the actual MAC address to the IP layer **POR 33-34, 35**
- **Incorrect:**

"There is no evidence in Chincholi that the actual MAC addresses of the RATs are "obscured"—rather, they are passed along and knowable to upper layers. EX2017 (Akl), ¶¶79-80; EX1005, [0142]."

POR at 33-34

"[0142] The MAC Resource Reservation module 602 may determine an amount of time duration and/or spectral fragment/bandwidth required by a packet or a set of packets. This module may transmit specific requests to the RATs over the A1/A2 interface."

Ex. 1005 (Chincholi) at [0142]; POR 34

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** Chincholi's OMMA passes the actual MAC address to the IP layer POR 33-34, 35
- **Incorrect:**

"In doing so, Chincholi's OMMA sends aggregated packets to the IP layer with the payload of each packet containing the actual MAC address of the RAT from where it originated. EX2017 (Akl), ¶79; EX1005, [0205] (OMMA layer uses "device address")."

POR at 35

"[0205] The OMMA Controller 2900 may comprise a Feedback Device Classifier module 2930. A RAT (e.g., each RAT) may provide feedback metrics (e.g., a vector comprising a value of serving rate, jitter, packet delay, and packet loss rate on its MAC) to the OMMA Controller 2900 per device (e.g., WTRU or NT) per access category supported at that RAT. This may be performed through interface A2 (e.g., as shown in FIG. 28). The Feedback Device Classifier module 2930 may classify the metrics for each device address (e.g., WTRU address or NT address), for example, so that the OMMA Controller 2900 may send feedback metrics to each device's OMMA layer (e.g., since each device may have different RAT capability), for example, through interface A5a (e.g., to a Feedback Based Scheduler (FBS) of OMMA Scheduler) and/or interface A5b (e.g., to a Policy Based Scheduler (PBS) of OMMA Scheduler) (e.g., as shown in FIG. 28)."

Ex. 1005 (Chincholi) at [0205]; POR at 35

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** Chincholi's OMMA passes the actual MAC address to the IP layer POR 33-34, 35

- **Incorrect:**

"In doing so, Chincholi's OMMA sends aggregated packets to the IP layer with the payload of each packet containing the actual MAC address (a "device address") of the RAT from where it originated. Indeed, a POSITA would understand that the OMMA layer communicates with the RAT protocol stacks, i.e., the MAC and PHY layers, by using the "device address," some examples of which are a WTRU (wireless transmit-receive unit) or NT (network terminal) address. Id., [0205], Fig. 5. A POSITA would understand that the OMMA layer also communicates to other components at each component's "device address," and that the components of the OMMA layer merely pass this device address along without obscuring it. See, e.g., id., [0142].

Ex. 2017 (Akl Decl.) at ¶79; Reply 14

"The portions of Chincholi that Dr. Almeroth cites only state that the OMMA may "combine[] packets from different RATs." EX1005, [0192]. This does not mean that the actual MAC addresses of the various RATs would be obscured; rather, they would be apparent as the OMMA forwarded them. Dr. Almeroth's description is not inconsistent with this; he merely does not account for the fact that a "virtual" MAC interface must obscure the actual MAC addresses when passing along a communication. Indeed, while Chincholi states that "the OMMA layer may be transparent," all this means is that it does not "add[] additional headers" as it would in "non-transparent" mode. Id. A POSITA would not understand the lack of additional headers to be not the same as obscuring an actual MAC address, nor would a POSITA understand it as "transparent"—which the parties here agree would mean being unaware of the operation of lower layers

Ex. 2017 (Akl Decl.) at ¶80; Reply 14

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** Chincholi's OMMA passes the actual MAC address to the IP layer POR 35
- **Incorrect:**

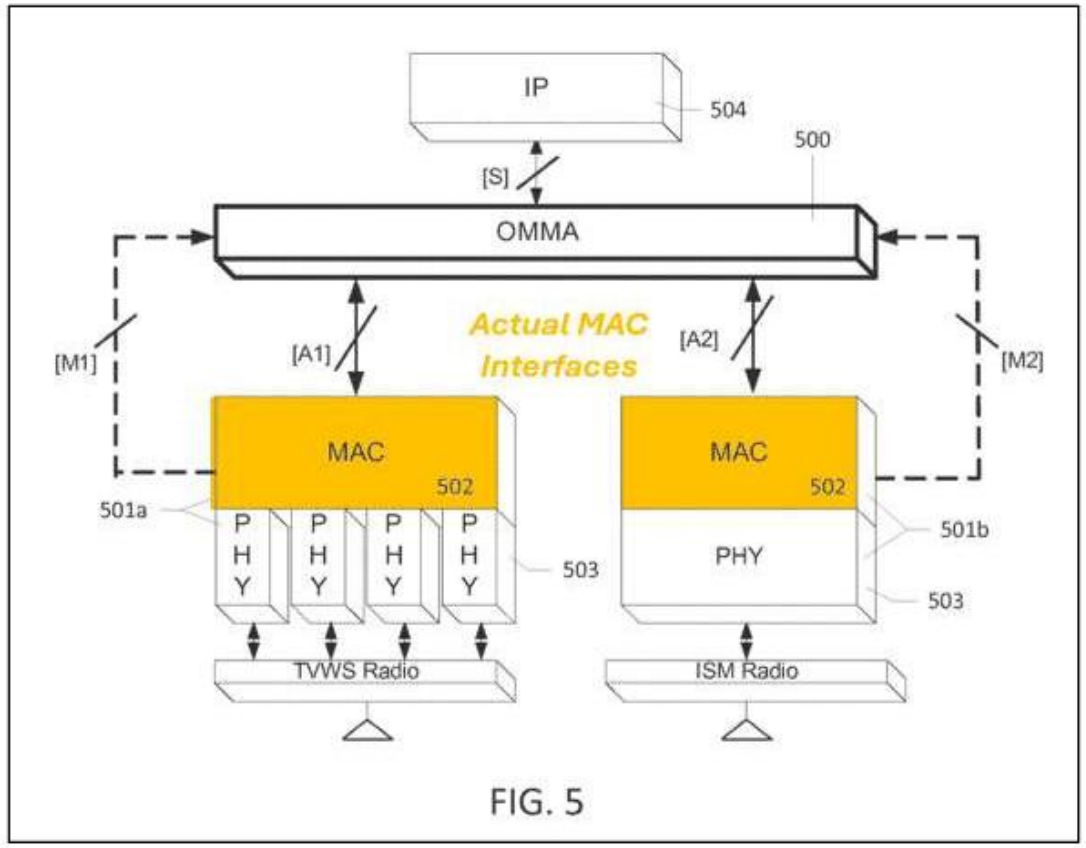


FIG. 5

Table 1

Interface	Description
M1	Meta-data/link statistics from TVWS band protocol stack to thin layer
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Ex. 1005 (Chincholi) at [0138]; Reply 6

"In the incoming direction, the 802.11 MAC sublayer would perform a de-encapsulation process in which the MAC header would be removed from the MPDU, leaving only the MSDU. The MSDU would then be passed to higher layers."

Ex. 1026 (Almeroth Supp. Decl.) at ¶47; Reply 6

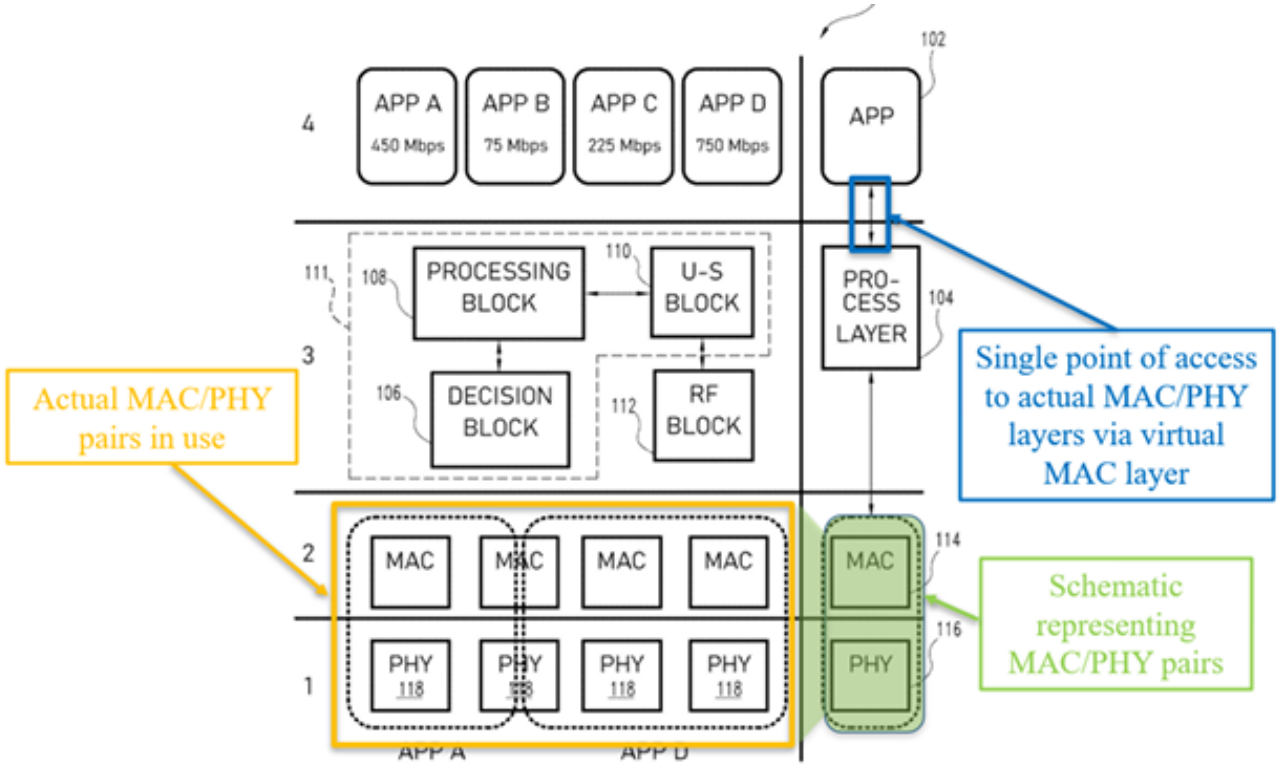
Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** OMMA resides on "layer 3"; ***patent requires it must be on layer 2*** **POR 37, 39-40, Surreply 9-10**

- **Incorrect:**
  - No such requirement in the patents
  - 564 patent expressly discloses processing layer above the actual MAC layer

"By employing a virtual MAC and virtual PHY between an application layer and an actual MAC and PHY layer, wireless transceiver resources may be allocated more efficiently to handle various data bandwidth requirements from different applications."

Ex. 1001 (564 patent) at 6:4-8; Pet. 26



Ex. 1001 (564 patent) at Fig. 1 (annotated by PO)

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** OMMA resides on "layer 3"; ***patent requires it must be on layer 2*** POR 37, 39-40, Surreply 9-10

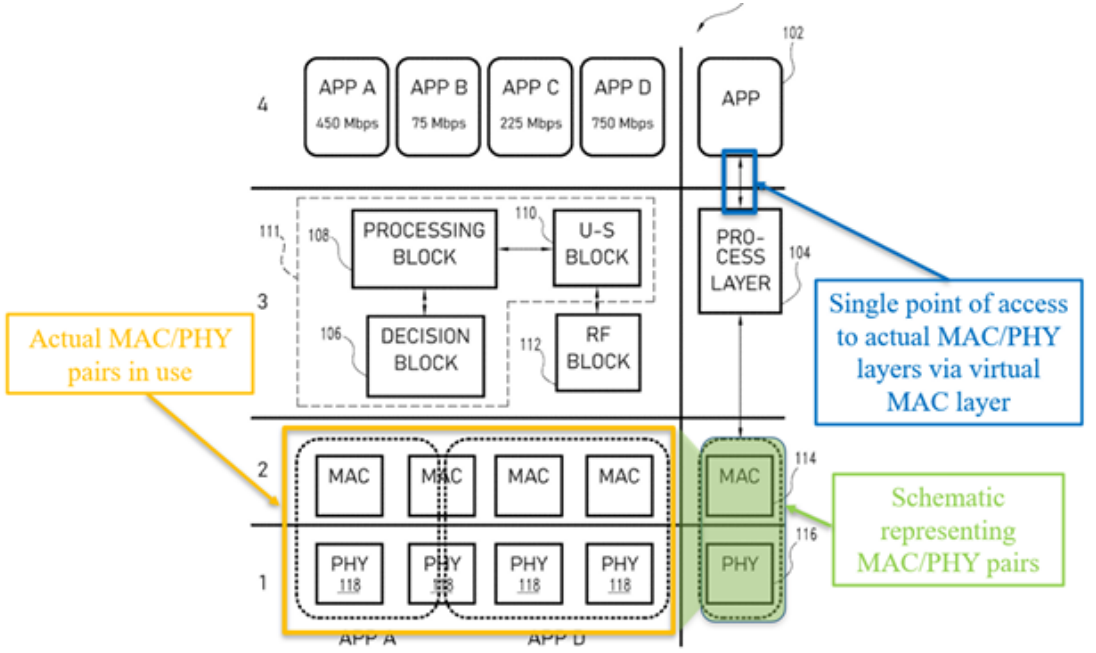
- **Incorrect:**

Agreed Construction: "virtual MAC interface"

"a software- or logical-based interface that is separately addressable from the recited actual MAC interfaces and that obscures the recited actual MAC interfaces from higher protocol stack layers"

"In this way, through the functioning of the virtual MAC layer, the higher layers receive the information that they are interacting with only one MAC/PHY pair—the virtual MAC interface—rather than the many actual MAC/PHY pairs below the virtual MAC interface:"

Ex. 2008 (Akl Decl.) at ¶64



Ex. 1001 (564 patent) at Fig. 1 (annotated by PO)

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** OMMA resides on "layer 3"; ***patent requires it must be on layer 2*** **POR 37, 39-40, Surreply 9-10**

- **Incorrect:**
  - PO's argument is based on its incorrect claim construction that the processing layer must be in "direct" communication with the actual MAC/PHY layers
  - District Court expressly rejected this position:

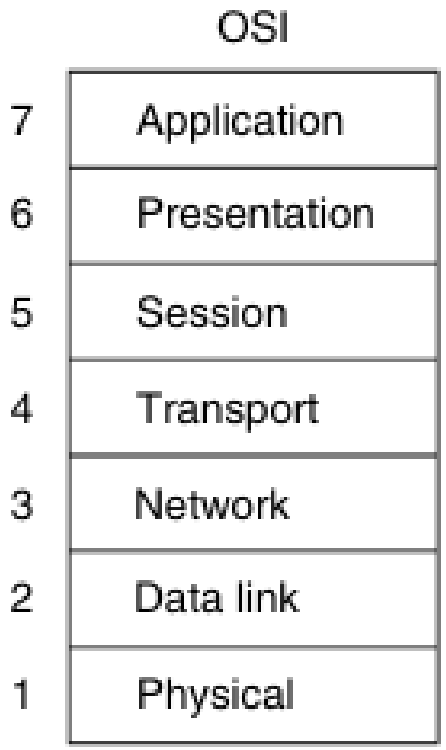
> "The Court agrees with Samsung, and it need not delve deep into the parties' arguments to do so. The disputed language states nothing about the *source* of the information. Rather, it limits the information's *content*. To change the plain meaning of the claim language requires lexicography or disavowal, neither of which XiFi asserts. And even to the extent a skilled artisan would understand the disclosed embodiments as communicating information directly from the transceivers to the processing layer, that is not what XiFi claimed."

Ex. 1027 at 16; Reply 20

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** OMMA resides on "layer 3"; ***patent requires it must be on layer 2*** **POR 37, 39-40, Surreply 9-10**

- **Incorrect:**



Ex. 2010 (Tanenbaum) at 62; POR 5

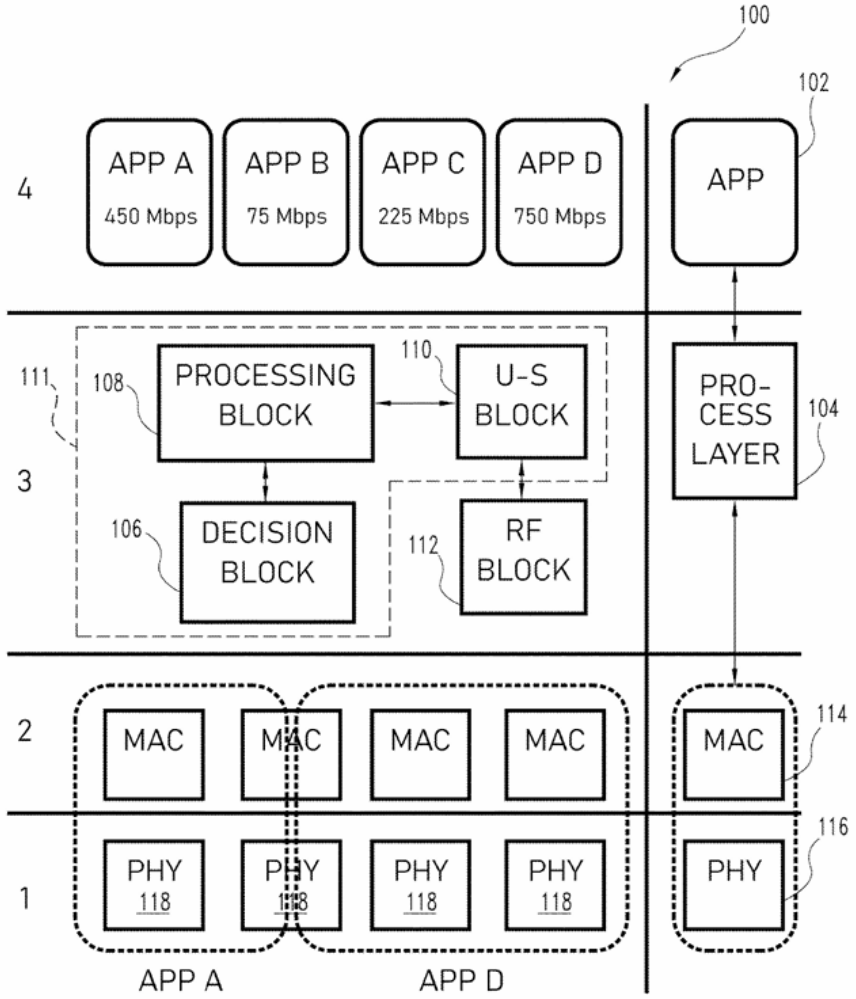


Fig. 1

Ex. 1001 (564 patent) at Fig. 1

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** OMMA resides on "layer 3"; ***patent requires it must be on layer 2*** **POR 37, 39-40, Surreply 9-10**
- **Incorrect:**

> "[A]lthough the claim recites connections among the processing interface, application interface, and actual MAC/PHY interfaces, it does not require the processing interface to be adjacent to the physical layer or located in any particular layer of the OSI model."

Ex. 1026 (Almeroth Supp. Decl.) at ¶26; Reply 3

> "[T]he claims do not recite the OSI model, Layer 2, the MAC sublayer, adjacency to the PHY layer, or any other specific protocol-stack location for the processing interface, virtual MAC interface, or resource monitoring interface."

Ex. 1026 (Almeroth Supp. Decl.) at ¶116; Reply 20

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:**
  - ***OMMA resides on "layer 3";*** patent requires it must be on layer 2 **POR 37, 39-40, Surreply 9-10**
  - Because it resides on layer 3, the OMMA does not obscure actual MAC interfaces from itself

- **Incorrect:** The OMMA's functionalities can also reside on layer 2:

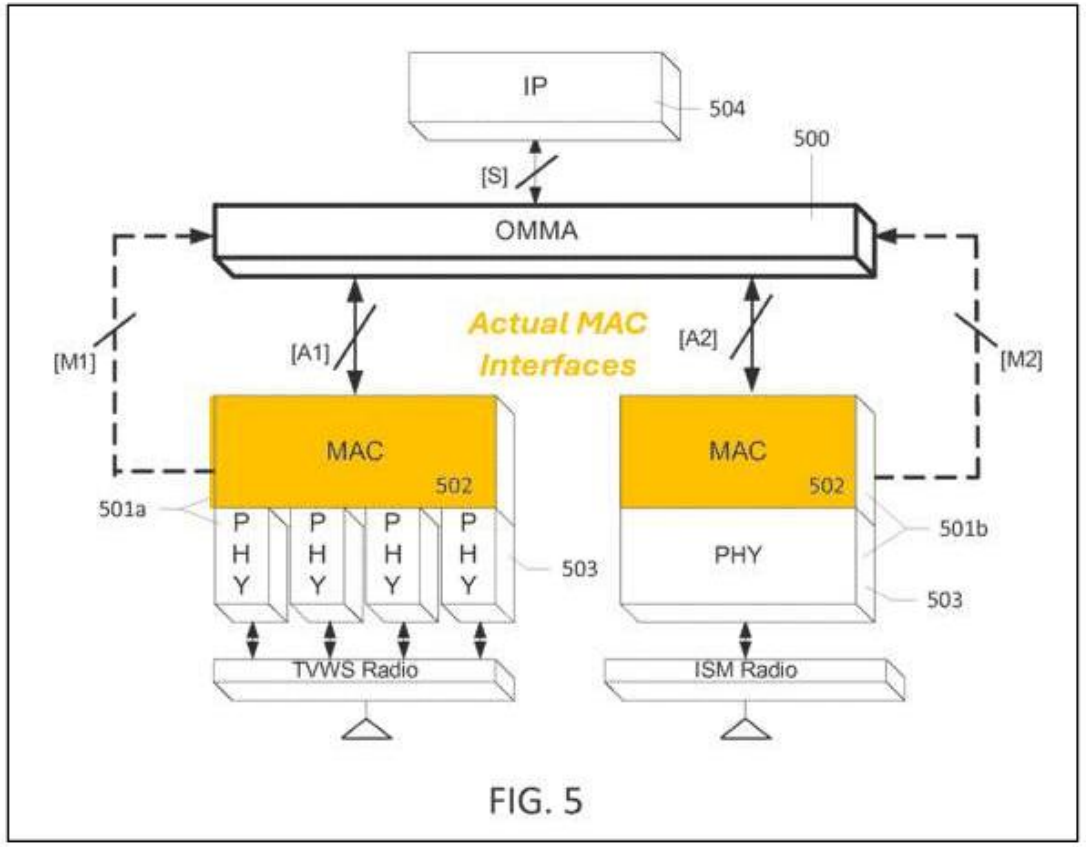


FIG. 5

"The OMMA layer (e.g., or OMMA module) may reside below the IP layer and above the radio protocol stacks. The OMMA layer may not be an independent layer, but rather the functionality of the OMMA layer may reside partially on one or more layers (e.g., the IP layer, the MAC layer, etc.) of the protocol stack."

Ex. 1005 (Chincholi) at [0122]; Reply 10

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **PO:** the OMMA does not direct the RATs because they "operat[e] independently" **POR 37**

- **Incorrect:**

> "A mechanism to aggregate two or more RATs operating independently on two or more bands to enhance the total IP throughput of the link may be described herein. For example, a single thin software layer (e.g., an opportunistic multi-medium access control (MAC) aggregation (OMMA) layer) may be described herein. For example, the single thin software layer may reside above the medium access control (MAC) layers of the protocol stacks but below the IP layer."

Ex. 1005 (Chincholi) at [0120]; Reply 6

- The RATs operate independently ***of each other*** which is why the OMMA is needed to direct their operation via coordination **Reply 9**

Chincholi discloses a "virtual MAC interface": "obscures actual MAC interfaces"

- **Surreply:** OMMA does not hide the existence of the interfaces of the actual MACs from higher layers **Surreply 10**

- **Incorrect:**
  - The only interface visible to the higher layers is OMMA's interface
    - All outgoing IP packets go to the OMMA
  - The higher layers cannot communicate with the actual MAC interfaces

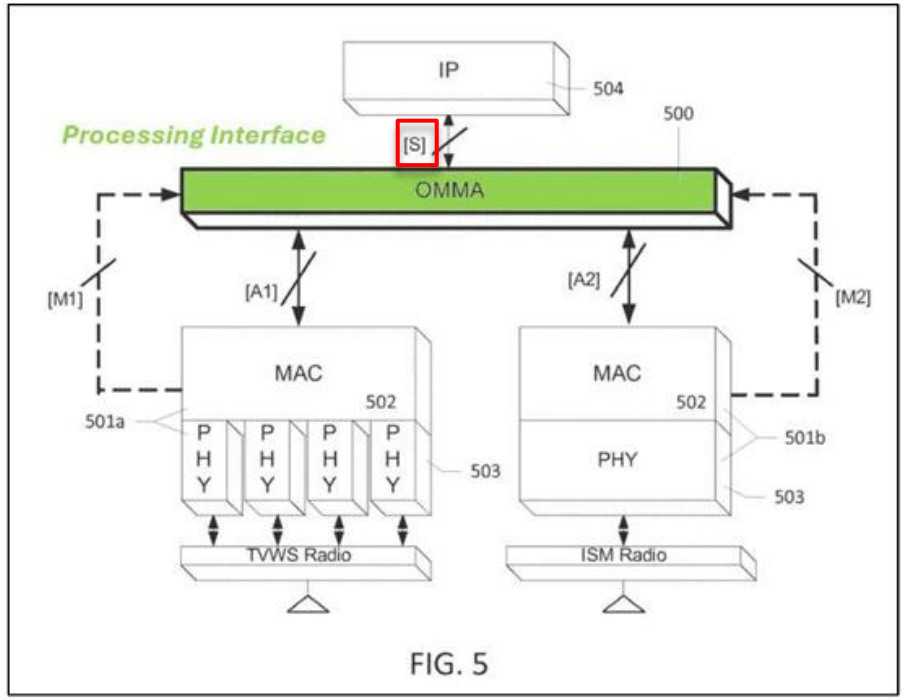


FIG. 5

Table 1

Interface	Description
M1	Meta-data/link statistics from TVWS band protocol stack to thin layer
M2	Meta-data/link statistics from ISM band protocol stack to thin layer
A1	Incoming/Outgoing MAC MSDUs on TVWS band, and MAC resource reservation control signaling
A2	Incoming/Outgoing MAC MSDUs on ISM band, and MAC resource reservation control signaling
S	Incoming/Outgoing IP Packets

Ex. 1005 (Chincholi) at [0138]; Reply 6

Chincholi discloses a “virtual MAC interface”: “obscures actual MAC interfaces”

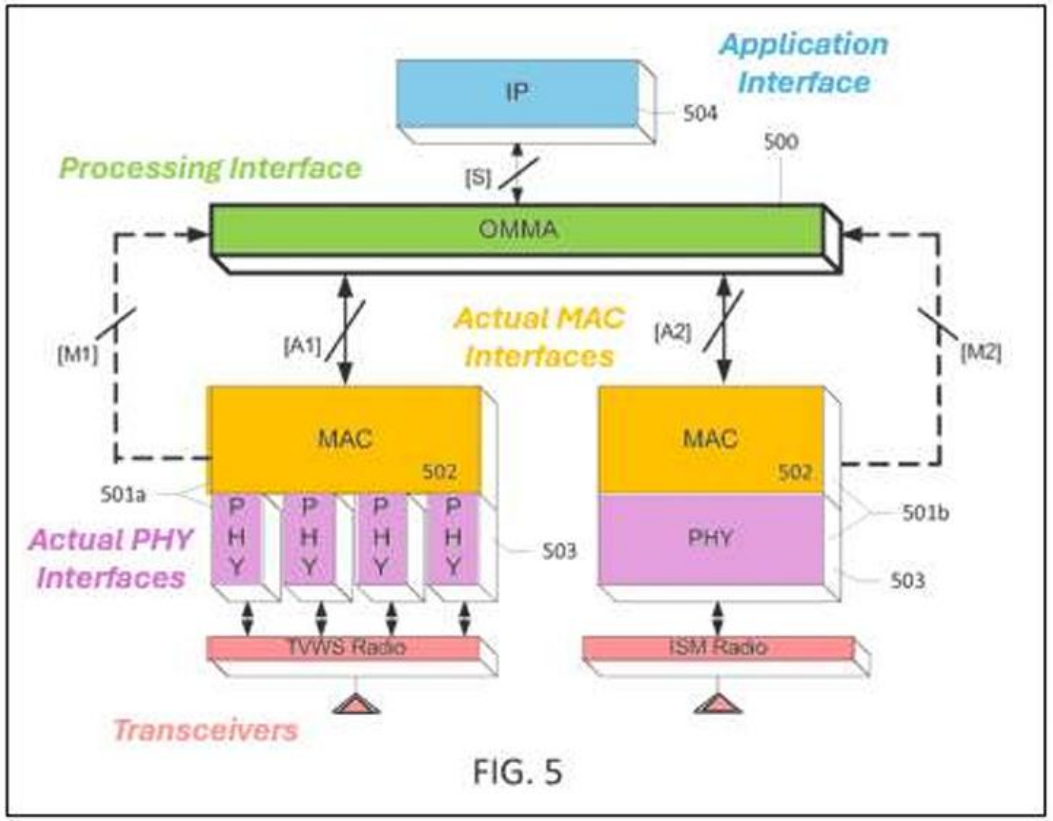
- **PO:** Chincholi’s OMMA is not a “virtual MAC interface” for other reasons
  - OMMA is not virtual **POR 34-35**
  - OMMA does not have the same functionality as the patent’s “decision block” **POR 38**
  - OMMA does not have the same functionality as the patent’s “processing block **POR 38**
  - OMMA does not have the same functionality as the patent’s “ultra-streaming block **POR 38**

- **Incorrect:**
  - OMMA’s components are virtual because they appear as a single interface to the higher layers despite multiple actual MAC interfaces
  - OMMA’s components perform decision block’s function of deciding the stream format
  - OMMA’s components perform the processing block’s function of processing the data stream
  - OMMA’s components the ultra-streaming block’s processing streams based on available resources

Chincholi discloses a "virtual MAC interface"

- **PO:** Chincholi does not call its OMMA "virtual" **POR 34-35**

- **Incorrect:** The OMMA's components are "virtual" because they appears as a single interface despite multiple actual MAC-PHY pairs



Ex. 1005 (Chincholi) at Fig. 5 (annotated)

"The OMMA layer includes an interface acting as a "virtual MAC interface" because it transparently "distributes and/or combines" packets between the IP layer and the RATs. (EX1005 ¶[0192].) A POSITA would have recognized that this "virtualizes" a MAC interface because the OMMA would effectively appear to the IP layer as a single interface for exchanging packets that are ultimately sent or received by the actual MAC-PHY pairs."

Ex. 1002 (Almeroth Decl.) at ¶102; Pet. 26

"For example, the single thin software layer may reside above the medium access control (MAC) layers of the protocol stacks but below the IP layer."

Ex. 1005 (Chincholi) at [0120]; Reply 6

Chincholi discloses a "virtual MAC interface"

- **PO:** the OMMA's "IP QoS Scheduler" does not perform the same functions as the patent's "decision block" **POR 38**

- **Incorrect:** IP QoS Scheduler performs decision block's function of putting stream into a particular stream format

"The decision block determines the size and type of data stream being received, and the type of processing necessary to put the stream in a format where it is capable of being transmitted. The processing block processes the data stream as determined by the decision block, and couples to an ultra-streaming block 110."

Ex. 1001 (564 patent) at 3:31-36; POR 38

"The IP QoS Scheduler 603 may segregate single IP packet stream comprising multiple IP QoS types into distinct IP QoS streams, for example, so that the traffic shaping module 601 may treat each IP QoS stream independently and satisfy the specific QoS requirements when routing IP packets."

Ex. 1005 (Chincholi) at [0143]; Pet. 27

- ***No dispute:*** Chincholi discloses claim 4

4. The wireless networking device of claim 1, wherein the at least one virtual MAC interface includes a decision block.

- Not addressed in surreply

Chincholi discloses a "virtual MAC interface"

- **PO:** the OMMA's MAC Resource Reservation does not perform the same functions as the patent's "processing block" **POR 38**

- **Incorrect:** MAC Resource Reservation performs the processing block's function of processing the data stream

"The processing block processes the data stream as determined by the decision block, and couples to an ultra-streaming block 110."

Ex. 1001 (564 patent) at 3:31-36; POR 38

"The MAC Resource Reservation module 602 may determine an amount of time duration and/or spectral fragment/bandwidth required by a packet or a set of packets. This module may transmit specific requests to the RATs over the A1/A2 interface."

Ex. 1005 (Chincholi) at [0142]; Pet. 28

- ***No dispute:*** Chincholi discloses claim 5

5. The wireless networking device of claim **1**, wherein the at least one virtual MAC interface includes a processing block.

- Not addressed in surreply

Chincholi discloses a "virtual MAC interface"

- **PO:** the OMMA's Traffic Shaping Module does not perform the same functions as the patent's "ultra-streaming block" POR 38

- **Incorrect:** Traffic Shaping Module performs the ultra-streaming block's function of processing streams based on available resources

"The ultra-streaming block manages the processing of signal streams or sub-streams given the available resources (memory, processing speed, number of available radios, etc.), and packetizes sufficiently processed streams or sub-streams."

Ex. 1001 (564 patent) at 3:36-40; POR 39

"The traffic shaping module 601 may [be] responsible for determining the way packets are routed across RATs. For example, the traffic shaping module may determine the way a packet is routed using policy based routing or feedback based routing."

Ex. 1005 (Chincholi) at [0139]; Pet. 28

- ***No dispute:*** Chincholi discloses claim 6

> **6**. The wireless networking device of claim **1**, wherein the at least one virtual MAC interface includes an ultra-streaming block.

- Not addressed in surreply

“information regarding the bandwidth availabilities”
(All Patents)

Chincholi discloses "information regarding bandwidth availabilities"

District Court Construction
"information regarding bandwidth availabilities"
"information regarding current bandwidth availabilities of each of the wireless transceivers"

- **PO:**
  - The term requires that the information be obtained "directly" from transceivers, which Chincholi does not disclose
  - Chincholi's OMMA does not receive ***current*** bandwidth availabilities, only historical

- PO is ***incorrect***:
  - The District Court rejected the requirement that information be obtained "directly"
  - Chincholi expressly discloses receiving "available bandwidth" and "available resources"
  - Chincholi expressly discloses receiving quality-of-service metrics, which affect bandwidth availability

Chincholi discloses "information regarding bandwidth availabilities"

- **PO:** the information must "be obtained directly" from the actual MAC/PHY interfaces

- After the POR, District Court ***rejected*** PO's construction:

> "The Court agrees with Samsung, and it need not delve deep into the parties' arguments to do so. The disputed language states nothing about the *source* of the information. Rather, it limits the information's *content*. To change the plain meaning of the claim language requires lexicography or disavowal, neither of which XiFi asserts. And even to the extent a skilled artisan would understand the disclosed embodiments as communicating information directly from the transceivers to the processing layer, that is not what XiFi claimed."

Ex. 1027 at 16; Reply 4

- PO's Surreply ***does not*** argue departure from the District Court's construction

> "[A]lthough the claim recites connections among the processing interface, application interface, and actual MAC/PHY interfaces, it does not require the processing interface to be adjacent to the physical layer or located in any particular layer of the OSI model."

Ex. 1026 (Almeroth Supp. Decl.) at ¶26; Reply 3

> "[T]he claims do not recite the OSI model, Layer 2, the MAC sublayer, adjacency to the PHY layer, or any other specific protocol-stack location for the processing interface, virtual MAC interface, or resource monitoring interface."

Ex. 1026 (Almeroth Supp. Decl.) at ¶116; Reply 20

Chincholi discloses "information regarding bandwidth availabilities"

- Chincholi discloses "***current*** bandwidth availabilities"

> "At startup, the OMMA layer may receive the available bandwidth of each of the one or more RATs. At the beginning of the ramp-up phase, the OMMA layer may receive RSSI values as seen by the one or more RATs. Following the ramp-up phase, the steady state-phase may start where the RAT modules at the transmitter OMMA layer may report metrics periodically or aperiodically."

Ex. 1005 (Chincholi) at [0167]; Reply 11

- **Surreply**: This disclosure refers to "total bandwidth" at startup, not "current bandwidth"

- **Incorrect:**
  - Chincholi expressly discloses OMMA receiving information about "available bandwidth"
  - PO ignores periodic updating of metrics after ramp-up
  - PO ignores RSSI, which impacts bandwidth availability and throughput

> "RSSI is a signal-quality measurement. A POSITA would have understood RSSI values received at the beginning of a ramp-up phase to reflect current channel conditions observed by the RATs at that time."

Ex. 1026 (Almeroth Supp. Decl.) at ¶66; Reply 11

Chincholi discloses "information regarding bandwidth availabilities"

- Chincholi discloses "***current*** bandwidth availabilities"

> "In dynamic RAT switching mode, the OMMA layer 1300 may select the best RAT possible (e.g., RAT 1301a) at any given time and not use the remaining RATs (e.g., RAT 1301b). For example, the OMMA layer 1300 may make this determination based on the instantaneous channel quality/availability of the RATs 1301a, 1301b."

Ex. 1005 (Chincholi) at [0154]; Reply 11

- **Surreply**: This disclosure relates to "quality of service," not bandwidth availability

- **Incorrect:**
  - Chincholi expressly discloses instantaneous channel ***availability***, not just quality
  - Quality affects bandwidth availability

Chincholi discloses "information regarding bandwidth availabilities"

- **PO:** Chincholi's feedback metrics are merely historical averages.

- **Incorrect:**

"In feedback based routing, the packets may be transmitted on different RATs using the feedback metrics. The feedback metrics may include, but are not limited to, RSSI, medium access delay, etc. The feedback metrics may reflect the average state of the system operating on each RAT."

Ex. 1005 (Chincholi) at [0141]; POR at 22

"In feedback based routing, the OMMA transmitter may use measurement metrics fed back from each RAT. The measurement metrics may include, but are not limited to, channel quality metrics and the number of available resources on the medium. The OMMA transmitter may utilized the measurement metrics to determine the instantaneous ratio of distribution of packets across the RATs. Table 2 provides examples of feedback metrics that may be used by an OMMA layer (e.g., an OMMA transmitter)."

Ex. 1005 (Chincholi) at [0161]; POR at 22

Table 2

Metric	Sender	Description
Medium Access Delay	MAC	Total packet delay in queue plus contention delay
RSSI	PHY	Received signal strength indication from PMD_RSSI.indication (*e.g.*, strength)
Frame error rate	MAC	Average rate at which packets are NACKed
Data rate	MAC	Average throughput
Queuing latency	MAC	Total packet delay in queue
End-to-end delay	MAC	Total delay from input to MAC at transmitter to output of MAC at receiver
TXOP duration	MAC	TXOP duration for video and voice access categories
AC with medium access	MAC	AC_BK, AC_BE, AC_VI, AC_VO, legacy
Backoff time	MAC	Random back off duration
Number of channels	PHY/MAC	Integer number of distinct channels
Channel bandwidth(s)	PHY/MAC	Vector/List of elements which are multiple of 0.5 MHz
MAC Aggregation Supported	MAC	Boolean: Yes, No
MAC Type	MAC	CSMA/CA, OFDMA, *etc.*

Chincholi discloses "information regarding bandwidth availabilities"

- **PO:** Chincholi's feedback metrics are merely historical averages.

- **Incorrect:**

> "[T]he feedback may include, but is not limited to, one or more of a medium access delay, jitter, a frame error rate, an average data rate, a received signal strength indication (RSSI) level, queuing latency per access category per RAT, end-to-end latency, a backoff time, a number of channels, channel bandwidth, a media access control (MAC) type, MAC aggregation support, an access category, a transmission opportunity (TXOP) duration, an estimated arrival rate of a packet, an average packet delay, packet loss rate (or frame error rate), queuing latency, number of MAC retransmissions, an average physical layer data rate, an average serving rate, an average serving latency, a serving delay variance, a second moment of average serving latency, vacation time, an average vacation time, a second average of vacation time, a vacation time variance, QoS ID, TCP parameters, such as sequence number, acknowledgement number, and window size, for example, etc."

Ex. 1005 (Chincholi) at [0215]; Reply 11

- PO's Surreply does not address this disclosure

“transparent” operation (All Patents)

Chincholi discloses “transparent” operation

Agreed Construction
“transparent to any layer”
“in a manner where any protocol stack layer of the wireless networking device above the processing interface is unaware of the operation of the processing interface”

- **PO:**
  - Chincholi’s “transparent mode” is described in a single sentence and does not indicate the OMMA obscures its operation

- PO is ***incorrect***:
  - Chincholi’s OMMA combines and routes packets to lower layers without higher layers being aware of its operation
  - PO’s Surreply does **not** address this limitation

Chincholi discloses “transparent” operation

- Difference between “transparent” and “obscures”:
- Virtual MAC interface “obscures” the actual MAC interfaces:

Agreed Construction
“virtual MAC interface”
“a software- or logical-based interface that is separately addressable from the recited actual MAC interfaces and that obscures the recited actual MAC interfaces from higher protocol stack layers”

- “Transparent” means higher layers unaware of operation of virtual MAC interface:

Agreed Construction
“transparent to any layer”
“in a manner where any protocol stack layer of the wireless networking device above the processing interface is unaware of the operation of the processing interface”

- Layers above processing interface see only the interface, not its operation or layers below it

Chincholi discloses "transparent" operation

- Chincholi's "transparent mode":

> "The OMMA layer ***may be transparent***, in that it distributes and/or combines packets from different RATs and forwards the packets to the IP layer."

Ex. 1005 (Chincholi) at [0192]; Reply 12

- Chincholi's higher layers are unaware of OMMA's reordering of packets:

> "When the receiving OMMA layer receives a packet it may remove the OMMA header and route the packet to the IP layer based on the information within the OMMA header. … As new packets are received, the packets that are being held, as a result of not being the next expected packet, may be re-evaluated to see if they are now the next expected packet. If they are the next expected packet, the OMMA layer may forward the packet to the IP layer without waiting for the timer to expire."

Ex. 1005 (Chincholi) at [0178]; Reply 13

> "The OMMA layer at the sender may use feedback from the MACs of each link to attempt to schedule the sending of the packets to maximize the likelihood that they are received in order, or as close as possible, to not trigger the congestion control mechanisms within TCP.

Ex. 1005 (Chincholi) at [0179]; Reply 13

- Not addressed in surreply

Chincholi discloses "transparent" operation

- **PO:** "transparent mode" does not obscure OMMA's operation POR 48

- **Incorrect:**

> "A POSITA would have understood that Chincholi's transparent mode allows the OMMA to perform its internal packet distribution, combination, routing, and RAT-selection operations while forwarding packets upward to the IP layer in a manner that does not require higher protocol-stack layers to be aware of those OMMA operations."

Ex. 1026 (Almeroth Supp. Decl.) at ¶74; Reply 13

> "When the receiving OMMA layer receives a packet it may remove the OMMA header and route the packet to the IP layer based on the information within the OMMA header. … As new packets are received, the packets that are being held, as a result of not being the next expected packet, may be re-evaluated to see if they are now the next expected packet. If they are the next expected packet, the OMMA layer may forward the packet to the IP layer without waiting for the timer to expire."

Ex. 1005 (Chincholi) at [0178]; Reply 13

- Not addressed in surreply

Chincholi discloses "transparent" operation

- **PO:** OMMA resides on layer 3, and so is only transparent to layers above layer 3 POR 48

- **Incorrect:**

Agreed Construction
"transparent to any layer"
"in a manner where any protocol stack layer of the wireless networking device above the processing interface is unaware of the operation of the processing interface"

"The OMMA layer (e.g., or OMMA module) may reside below the IP layer and above the radio protocol stacks. The OMMA layer may not be an independent layer, but rather the functionality of the OMMA layer may reside partially on one or more layers (e.g., the IP layer, the MAC layer, etc.) of the protocol stack."

Ex. 1005 (Chincholi) at [0122]; Reply 14

“do not prevent” other devices from using “remaining portion of the bandwidth availability”
(All except ‘756 and ‘198 patents)

Chincholi "do[es] not prevent" use of remaining bandwidth

Limitation
Device's utilization of bandwidth "do not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the first wireless transceiver"

- **PO:**
  - Chincholi does not disclose multiple devices sharing a single MAC/PHY pair at the same time

- PO is ***incorrect***:
  - Chincholi teaches that a transceiver's MAC layer can assign multiple packets for multiple devices to a single buffer
  - Chincholi also teaches OFDMA, which allows multiple devices to simultaneously access different channels of a transceiver

Chincholi "do[es] not prevent" use of remaining bandwidth

- Patent Owner agrees that this limitation only requires multiple devices communicating with a single MAC/PHY pair:

> "A POSITA would understand this to mean that two devices or two applications could share a single MAC/PHY pair at the same time."

POR at 51

- Chincholi:

> "Although sender IP packets may be forwarded to the sender MAC layer as a single stream, the MAC layer may sort them according to their corresponding access categories and/or WTRU addresses. The main IP stream for each WTRU 310 may be split into one or more QoS streams that may be queued in separate buffers in the sender MAC layer."

Ex. 1005 (Chincholi) at [0351]; Pet. 43

Chincholi "do[es] not prevent" use of remaining bandwidth

- Chincholi also discloses that a MAC layer can use OFDMA:

Table 2

Metric	Sender	Description
Medium Access Delay	MAC	Total packet delay in queue plus contention delay
RSSI	PHY	Received signal strength indication from PMD_RSSI.indication (*e.g.*, strength)
Frame error rate	MAC	Average rate at which packets are NACKed
Data rate	MAC	Average throughput
Queuing latency	MAC	Total packet delay in queue
End-to-end delay	MAC	Total delay from input to MAC at transmitter to output of MAC at receiver
TXOP duration	MAC	TXOP duration for video and voice access categories
AC with medium access	MAC	AC_BK, AC_BE, AC_VI, AC_VO, legacy
Backoff time	MAC	Random back off duration
Number of channels	PHY/MAC	Integer number of distinct channels
Channel bandwidth(s)	PHY/MAC	Vector/List of elements which are multiple of 0.5 MHz
MAC Aggregation Supported	MAC	Boolean: Yes, No
MAC Type	MAC	CSMA/CA, OFDMA, *etc.*

Ex. 1005 (Chincholi) at [0161]; Pet. 43

Chincholi "do[es] not prevent" use of remaining bandwidth

- OFDMA allows multiple devices to transmit simultaneously on different frequencies:

"OFDMA stands for "Orthogonal Frequency Division Multiple Access," which was a known wireless communication technique for dividing an available bandwidth into smaller subcarriers (i.e. frequency ranges) which are then allocated to different users. These subcarriers are described as orthogonal because they do not interfere with each other when simultaneously transmitted. A POSITA would have recognized that OFDMA techniques would allow multiple WTRUs to access different channels of the transceiver resources simultaneously and without interference."

Ex. 1002 (Almeroth Decl.) at ¶134; Pet. 43

"A POSITA would have understood OFDMA to be a multiple-access technique in which different users may be assigned different orthogonal frequency resources within available bandwidth. Because those frequency resources are orthogonal, different users may transmit or receive using different allocated resources without one user's allocation preventing another user from using remaining allocated resources."

Ex. 1026 (Almeroth Supp. Decl.) at ¶84; Reply 14

- PO does not dispute that OFDMA performs bandwidth sharing

Choi discloses "do not prevent" use of remaining bandwidth

- **PO's Surreply:**
  - Chincholi only operates in pre-OFDMA 802.11 standards **Surreply 16**
  - OFDMA ***cannot be*** implemented in 802.11 **Surreply 16**

- **PO is incorrect:** Chincholi discloses cellular standards that used OFDMA:

> "As described herein, a RAT may be, for example, a WiFi RAT, an LTE RAT, a WCDMA/HSPA RAT, an UTRAN RAT, an E-UTRAN RAT, etc. A Wi-Fi RAT may be a IEEE802.1 In RAT, a IEEE802.1 lac RAT, a IEEE802.1 laf RAT, etc. An LTE RAT may be a LTE Rel-8 compliant RAT, a LTE-A Rel-10 compliant RAT, etc. A WCDMA RAT may be a WCDMA R4 compliant RAT, a WCDMA/HSDPA/HSUPA Rel6 RAT, etc.

Ex. 1005 (Chincholi) at [0134]; Pet. 23, Reply 14-15, EX1026 ¶¶83-86

- In addition, OFDMA could be implemented in 802.11:

> "It was also well-known to a POSITA at this time that OFDMA could be implemented with then-existing IEEE 802.11 systems. Thus, Chincholi's discussion of OFDMA in an IEEE 802.11 communications system would be understood as a possible, conventional implementation and well within the ordinary skill in the art."

Ex. 1026 (Almeroth Supp. Decl.) at ¶85; Reply 14

Choi discloses "do not prevent" use of remaining bandwidth

- **PO's Surreply:**
  - Chincholi only operates in pre-OFDMA 802.11 standards **Surreply 16**
  - OFDMA ***cannot be*** implemented in 802.11 **Surreply 16**

> "Rather, Petitioners rely solely on the fact that Chincholi uses the word "OFDMA" without explaining how OFDMA would be implemented within Chincholi. Id. at 14-15. Chincholi discloses operating only in pre-OFDMA 802.11 standards; nor do Chincholi, Petitioners, or their expert describe how a POSITA would know to modify those standards to allow for implementation of OFDMA. EX1005, [0116]; EX2017, ¶103; POR at 55."

Surreply 16

Chincholi "do[es] not prevent" use of remaining bandwidth

- **PO:** Chincholi does not use OFDMA because it describes devices "contend[ing] with each other"

- **PO is incorrect:** Chincholi discloses no contention if ***different*** frequencies:

> "WTRUs operating on an ISM band may contend with each other for ISM channel access. WTRUs operating over a TVWS band may contend with each other for TVWS channel access. WTRUs operating over an ISM band and WTRUs operating over a TVWS band may not contend with each other, for example, since they are on different operating frequencies."

Ex. 1005 (Chincholi) at [0117]; Reply 15

- OFDMA shares bandwidth by transmitting on different, ***orthogonal*** frequencies:

> "OFDMA stands for "Orthogonal Frequency Division Multiple Access," which was a known wireless communication technique for dividing an available bandwidth into smaller subcarriers (i.e. frequency ranges) which are then allocated to different users. These subcarriers are described as orthogonal because they do not interfere with each other when simultaneously transmitted."

Ex. 1002 (Almeroth Decl.) at ¶134; Reply 23

Chincholi "do[es] not prevent" use of remaining bandwidth

- PO's Expert Dr. Akl:

> "A POSITA would understand that transmission in a system such as that of the '564 Patent takes place during set "transmission opportunities," or TXOPs. See EX2010 at 309. A POSITA would further understand that, in parallel transmissions on two different bands, both transmissions would take place during a given TXOP. A POSITA would understand that two parallel transmissions could not be perfectly simultaneous as a matter of physical reality, but could be "substantially," or essentially, simultaneous—where the two parallel transmissions were transmitting the same amount of frames during the TXOP span. Id. A POSITA would further understand that, if the two transmissions were of different data amounts, the one transmitting less data would finish first within the TXOP's duration. Id. This would mean the transmissions were "partially simultaneous"— overlapping while both were transmitting, but not fully or substantially—because the larger transmission would take longer to finish."

Ex. 2017 (Akl Decl.) at ¶152; Reply 26

“without requiring disassociation”
(All except ‘756 and ‘198 patents)

Chincholi uses multiple transceivers "without requiring disassociation"

Limitation
"use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces"

- **PO:**
  - Patent requires "make before break," but convention was "break before make"
  - Chincholi disables low quality RATs before switching to a different RAT which is "break before make"

- PO is ***incorrect***:
  - Chincholi expressly teaches duplicating packets on multiple RATs to transmit
  - Chincholi does not teach that low quality RATs are disabled before switching

Chincholi uses multiple transceivers "without requiring disassociation"

- Chincholi teaches that when a RAT switch occurs, packets are duplicated on multiple RATs:

> "After determining the RATs that are available for the WTRU (e.g., through the STA_RAT_Capability_Response_A4 signal on interface A4), the PBS module 3210 may select (e.g., randomly select) a RAT other than the current selected RAT from the RAT availability list. When a RAT switch occurs, the PBS module 3210 may signal the FBS module 3230 to duplicate one or more packets across the RATs to avoid out-of-order packet reception at the OMMA receiver."

Ex. 1005 (Chincholi) at [0255]; Reply 39

- Chincholi teaches duplication is to "enable a soft handover"

> "When a RAT switch occurs, the FBS may duplicate one or more packets across one or more RATs (e.g., two RAT, for example, a RAT which is not able to fulfil the QoS requirement and a RAT chosen to replace this RAT) to enable a soft handover across RATs and/or avoid out-of-order packet reception at OMMA receiver."

Ex. 1005 (Chincholi) at [0381]; Reply 16

- Chincholi clearly teaches that multiple RATs are still used during a switch, and therefore disassociation is not required

Chincholi uses multiple transceivers "without requiring disassociation"

- **PO:** Chincholi ***requires*** RAT to be disabled ***before*** switching, a.k.a. "break before make" POR 56-57
- **Incorrect:** Chincholi only discloses disabling a "low channel quality" RAT and that it is ***optional***:

> "As the channel quality/availability of RATs 1301a, 1301b changes, the best RAT may be selected which may be different from the one previously used. For example, if the channel quality of one RAT is 6dB or lower than the channel quality of the other RATs, the RAT with the low channel quality may be disabled."

Ex. 1005 (Chincholi) at [0155]; Reply 16

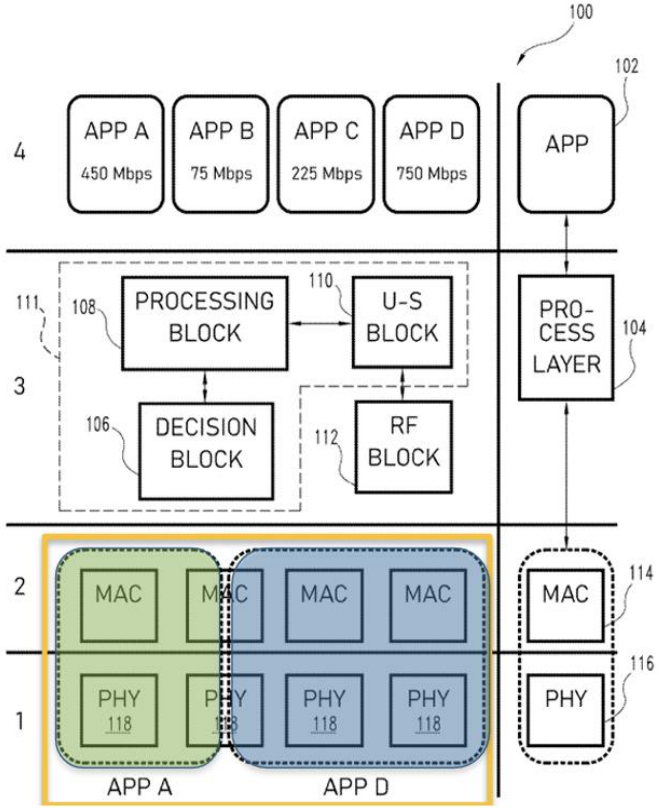
Chincholi uses multiple transceivers "without requiring disassociation"

- **PO:** Chincholi would be understood to be "break before make" in view of what was "typical" at the time **POR 56-57**

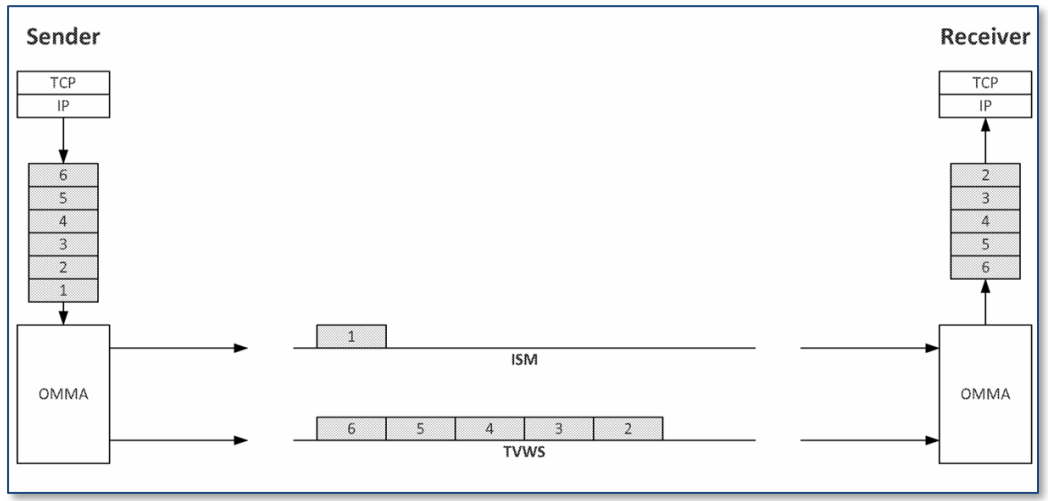
- **Incorrect:** This is inconsistent with Dr. Akl's testimony regarding 564 patent's Figure 1 **Reply 26**

"From the fact that each application is using multiple radios/transceivers, a POSITA would understand that "make before break" is being employed."

Ex. 2017 (Akl Decl.) at ¶145



Ex. 1001 (564 patent) at Fig. 1 (annotated by PO)



Ex. 1005 (Chincholi) at Fig. 19; Reply 6

Chincholi uses multiple transceivers "without requiring disassociation"

- **Surreply:** Duplicating packets does not suggest both RATs will form associations with the actual MAC/PHY interfaces **Surreply 16**

> "Petitioners point to passages in Chincholi where multiple RATs carry certain duplicated packets, id. (citing EX1005, [0255], [0381]), but this does not suggest that both RATs carrying the duplicated packets will form associations with the actual MAC and PHY interfaces."

Surreply 16

- **Incorrect:** The claimed associations are between the ***recipient*** and the actual MAC/PHY interfaces, not between the ***RATs*** and the actual MAC/PHY interfaces

(c) if the data transfer characteristics of the first identified bandwidth portion of the first wireless transceiver are better than the data transfer characteristics of the first identified bandwidth portion of the second wireless transceiver, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using

Chincholi uses multiple transceivers "without requiring disassociation"

- **Surreply:** Duplicating packets does not suggest both RATs will form associations with the actual MAC/PHY interfaces **Surreply 16**

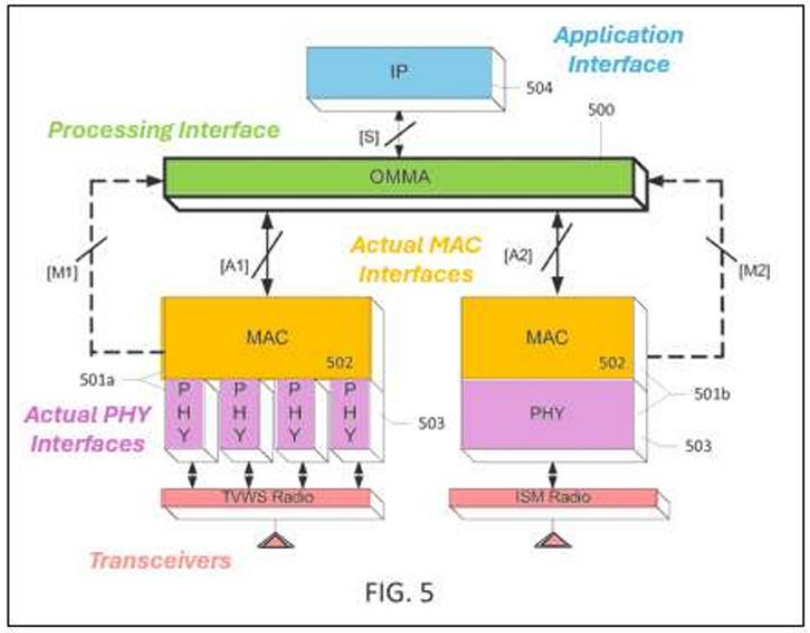
> "Petitioners point to passages in Chincholi where multiple RATs carry certain duplicated packets, id. (citing EX1005, [0255], [0381]), but this does not suggest that both RATs carrying the duplicated packets will form associations with the actual MAC and PHY interfaces."

POR 16

- **Incorrect:** In Chincholi, the RATs ***are*** the actual MAC/PHY interfaces

> "The RATs 501a, 501b may comprise a MAC layer/module 502 and one or more physical layers/modules 503."

Ex. 1005 (Chincholi) at [0138]; Reply 6



Ex. 1005 (Chincholi) at Fig. 5

Motivation to Combine Chincholi and Riggert

Motivation to Combine: Chincholi + Riggert

IPR No.	Patent No.	Combination
IPR2025-01203	11,849,337	Chincholi, Riggert
IPR2025-01204	11,818,591	Chincholi, Riggert
IPR2025-01205	12,003,976	Chincholi, Riggert, Clegg
IPR2025-01206	11,950,105	Chincholi, Riggert, Clegg
IPR2025-01207	12,015,933	Chincholi, Riggert, Clegg
IPR2025-01208	11,974,143	Chincholi, Riggert
IPR2025-01209	11,856,414	Chincholi, Riggert

Motivation to Combine: Chincholi + Riggert

- **PO:**
  - Riggert does not teach a "virtual PHY interface" that provides feedback information
  - Riggert's feedback information is sent across a device
  - Chincholi's OMMA is layer 3, preventing "virtual PHY interface" from direct communication with actual PHY interfaces on layer 1
  - Chincholi would have included virtual PHY interface if it was well-known
  - Combination driven by hindsight

- PO is ***incorrect***:
  - The petitions propose incorporating Riggert into Chincholi's feedback architecture
  - Riggert does provide feedback to the same device
  - OMMA does not have to be layer 3, and "direct" communication is not necessary
  - Chincholi's does disclose virtualizing the actual PHY interfaces
  - Petitions use a concrete, non-hindsight reason to combine

Motivation to Combine: Chincholi + Riggert

- Limitation: "virtual PHY interfaces" rendered obvious by Chincholi alone

"Figures 28, 29, and their associated descriptions describe how Chincholi collects feedback from each RAT for the traffic shaping module. Figure 28 illustrates how the OMMA layer includes an OMMA Controller, which interfaces with each RAT to collect metrics regarding the channel quality and number of resources available on the medium. Specifically, using interface "A2" in Figure 28, "[a] RAT (e.g., each RAT) may provide feedback metrics (e.g., a vector comprising a value of serving rate, jitter, packet delay, and packet loss rate on its MAC) to the OMMA Controller 2900 per device (e.g., WTRU or NT) per access category supported at that RAT." (EX1005 at [0205].) It would have been obvious to a POSITA to incorporate first and second virtual PHY interfaces into the OMMA Controller of Chincholi to collect the disclosed feedback metrics from each RAT over the "A2" interface and feed them back to the virtual MAC interface.

337 Ex. 1002 (Almeroth Decl.) at ¶104; 337 Pet. 29

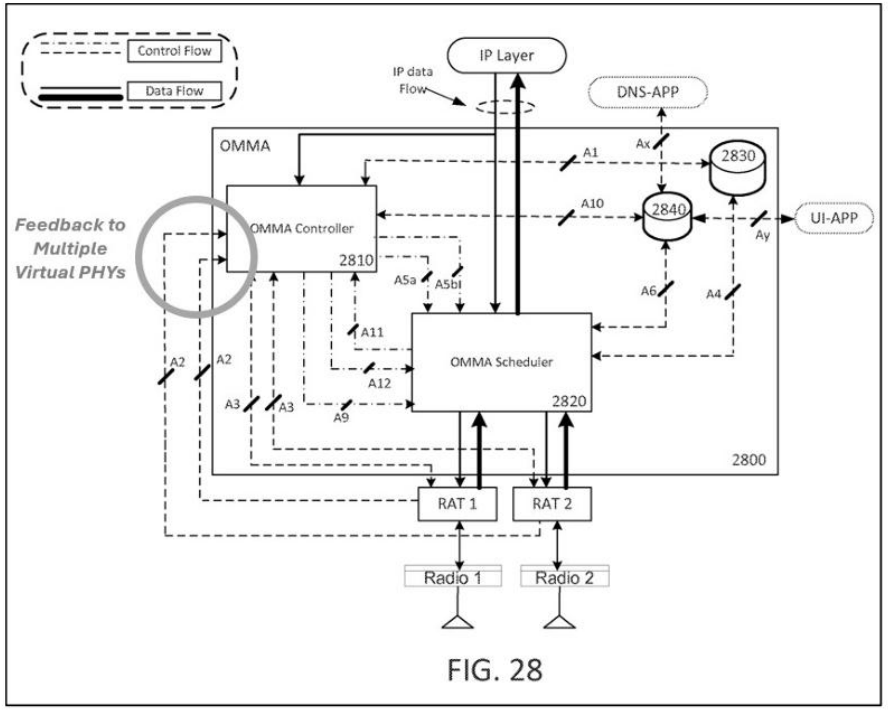


FIG. 28

Ex. 1005 (Chincholi) at Fig. 5 (annotated)

Motivation to Combine: Chincholi + Riggert

- Riggert provides additional details of "virtual PHY interfaces"

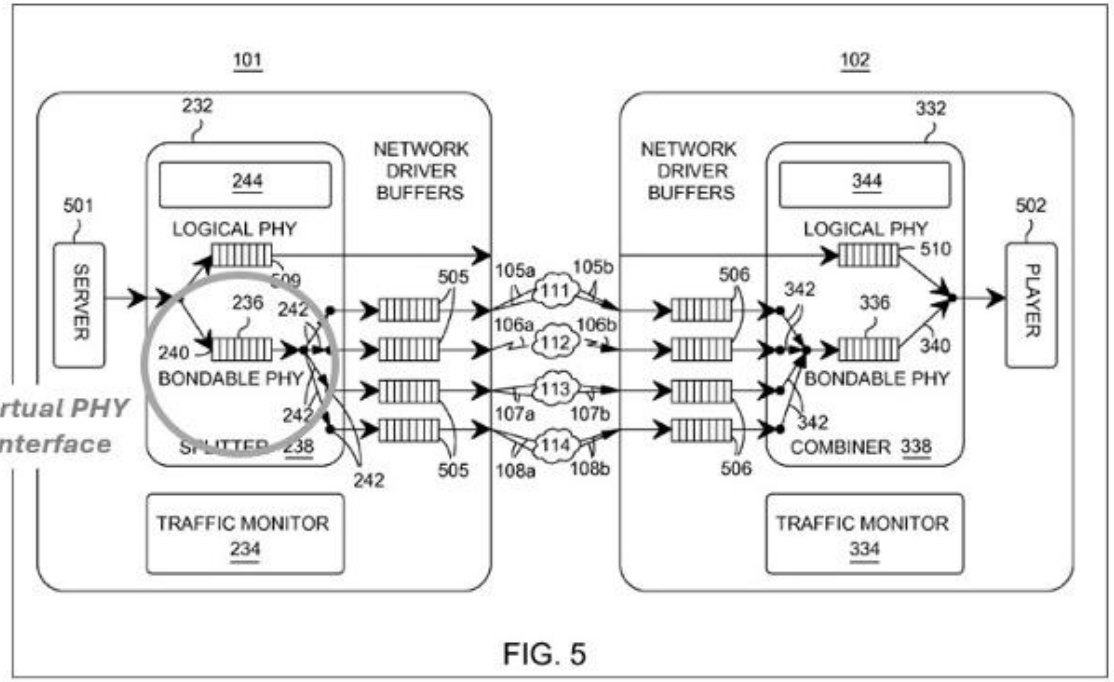


FIG. 5

Ex. 1006 (Riggert) at Fig. 5 (annotated); 337 Pet. 31

"Each bondable virtual interface connector is associated with a specific bondable virtual interface. The bondable virtual interface connectors 244 and 344 ensure that the connections between the software libraries 232 and 332 and the multiple physical interfaces 105a to 108a and 105b to 108b via the multiple endpoint channels 242 and 342, respectively, are ready to accept data before sending data from the sending endpoint 101 to the receiving endpoint 102."

Ex. 1006 (Riggert) at [0069]; 337 Pet. 30

Motivation to Combine: Chincholi + Riggert

- A POSITA would have a motivation to combine Chincholi with Riggert's virtual PHY interfaces

> "In my opinion, Riggert's "bondable virtual interface" would improve the system of Chincholi by providing a flexible, universal interface between the OMMA layer and the actual transceiver resources. (EX1006 at [0065] ("The bondable virtual interfaces 236 and 336 conform to an interface, which allows them to be used generically in the framework.").) The combined system would improve Chincholi by providing a universal interface between the OMMA controller and sets of potentially differently configured RATs, a benefit that cannot be achieved alone by Chincholi's system. This combination would allow Chincholi's system to operate seamlessly with a wider variety of recipient devices operating on different versions of the 802.11 standards."

337 Ex. 1002 (Almeroth Decl.) at ¶73; 337 Pet. 13

Motivation to Combine: Chincholi + Riggert

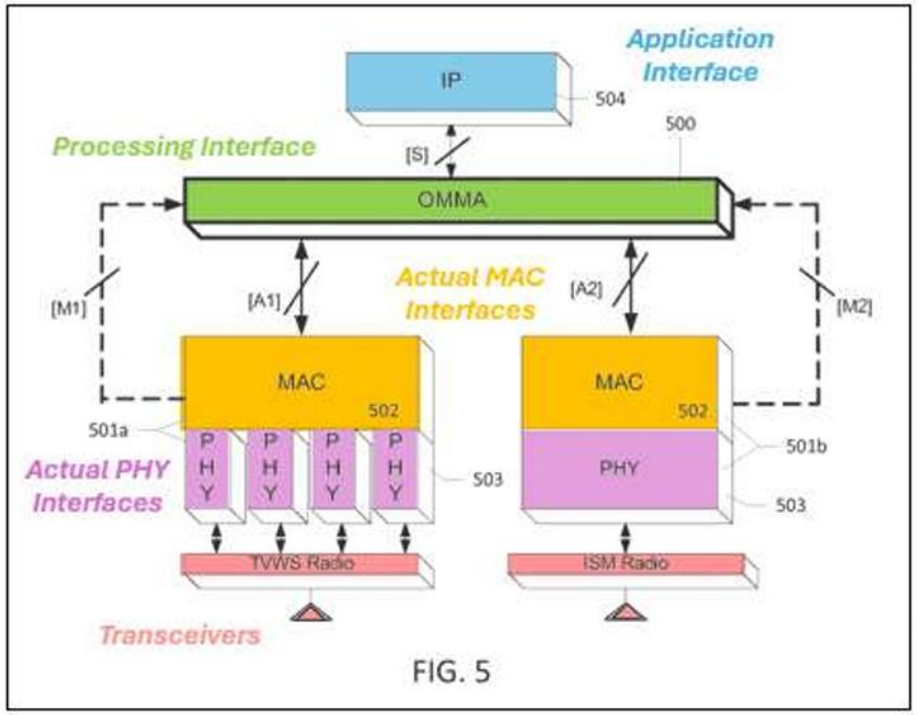
- **PO:** Riggert's virtual PHY transmits streaming data, not feedback information 337 POR 58-59

- **The Petition relies on Chincholi's feedback, cites to Rigget as additional support**

- Riggert teaches a virtual PHY interface that can be used with any actual PHY configuration
- The Petitions propose combining Riggert's virtual PHY interface with Chincholi's OMMA, including ***Chincholi's*** feedback architecture:

"It would have been obvious to a POSITA to incorporate first and second virtual PHY interfaces into the OMMA Controller of Chincholi to collect the disclosed feedback metrics from each RAT over the 'A2' interface and feed them back to the virtual MAC interface."

337 Ex. 1002 (Almeroth Decl.) at ¶104; 337 Pet. 29



Ex. 1005 (Chincholi) at Fig. 5 (annotated)

Motivation to Combine: Chincholi + Riggert

- **PO:** Riggert's virtual PHY transmits feedback across devices 337 POR 59-60
- **Incorrect:** Riggert teaches feedback being sent to its "traffic proxy"

"[T]he bondable virtual interface 236 gathers information regarding data sent over the multiple data communication channels, and sends the data information to the traffic proxy 248. The traffic proxy 248 then sends the data information to the traffic monitor 234."

Ex. 1006 (Riggert) at ¶[0113]; 337 Reply at 19-20

"A POSITA would recognize that information gathered by the bondable virtual interface and provided to a traffic monitor is feedback information regarding communications over the multiple data communication channels."

Ex. 1026 (Almeroth Supp. Decl.) at ¶105; 337 Reply at 19

Motivation to Combine: Chincholi + Riggert

- **PO:** Chincholi's OMMA is layer 3, preventing the virtual PHY from direct communication with actual PHY interfaces **337 POR 59-60**

- **Incorrect:** Chincholi's OMMA is not layer 3, and direct communication is not required

> "The OMMA layer (e.g., or OMMA module) may reside below the IP layer and above the radio protocol stacks. The OMMA layer may not be an independent layer, but rather the functionality of the OMMA layer may reside partially on one or more layers (e.g., the IP layer, the MAC layer, etc.) of the protocol stack."

Ex. 1005 (Chincholi) at [0122]; 337 Reply 10

> "The Court agrees with Samsung, and it need not delve deep into the parties' arguments to do so. The disputed language states nothing about the *source* of the information. Rather, it limits the information's *content*. To change the plain meaning of the claim language requires lexicography or disavowal, neither of which XiFi asserts. And even to the extent a skilled artisan would understand the disclosed embodiments as communicating information directly from the transceivers to the processing layer, that is not what XiFi claimed."

Ex. 1027 at 16; 337 Reply 4

Motivation to Combine: Chincholi + Riggert

- **PO:** If virtualization was well-understood, Chincholi would have included virtual PHY interfaces 337 POR 62

- **Incorrect:** Chincholi's OMMA virtualizes the actual PHY interfaces and is therefore would be obvious to incorporate virtual PHY interfaces

> "Specifically, using interface "A2" in Figure 28, "[a] RAT (e.g., ***each RAT***) may provide feedback metrics (e.g., a vector comprising a value of serving rate, jitter, packet delay, and packet loss rate on its MAC) to the OMMA Controller 2900 ***per device (e.g., WTRU or NT) per access category supported at that RAT."*** (EX1005 at [0205].) It would have been obvious to a POSITA to incorporate first and second virtual PHY interfaces into the OMMA Controller of Chincholi to collect the disclosed feedback metrics from each RAT over the "A2" interface and feed them back to the virtual MAC interface."

337 Ex. 1002 (Almeroth Decl.) at ¶104; 337 Pet. 29

Motivation to Combine: Chincholi + Riggert

- **PO:** Combination is driven by hindsight 337 POR 60

- **Incorrect:** Petition identified a concrete, non-hindsight reason to combine

> "Chincholi already contemplates multiple 802.11 RATs, including RATs based on different 802.11 generations. A POSITA would have understood that virtualized PHY interfaces between Chincholi's OMMA layer and those RATs would provide a flexible, reconfigurable, and generic interface for differently configured PHY interfaces.
>
> Applying Riggert's virtualized-interface teaching to Chincholi would therefore have predictably improved Chincholi's multi-RAT system by increasing flexibility and interoperability with different recipient devices and networks. This is a predictable use of a known virtualized-interface technique to improve Chincholi's feedback-based multi-RAT architecture, not hindsight reconstruction."

337 Ex. 1026 (Almeroth Supp. Decl.) at ¶¶107-08; 337 Reply 21

Motivation to Combine Chincholi and Clegg

Motivation to Combine: Chincholi + Clegg

IPR No.	Patent No.	Combination
IPR2025-01205	12,003,976	Chincholi, Riggert, Clegg
IPR2025-01206	11,950,105	Chincholi, Riggert, Clegg
IPR2025-01207	12,015,933	Chincholi, Riggert, Clegg
IPR2025-01270	12,114,177	Chincholi, Clegg
PGR2025-00067	12,190,198	Chincholi, Clegg
PGR2025-00068	12,169,756	Chincholi, Clegg
PGR2025-00069	12,250,564	Chincholi, Choi, Clegg

Motivation to Combine: Chincholi + Clegg

- **PO:**
  - A POSITA would not be motivated to combine Chincholi with Clegg "ultra-wideband tuner"
  - Clegg does not teach "without requiring disassociation"

- PO is ***incorrect***:
  - The petitions do not propose using Clegg's ultra-wideband tuner
  - The petitions do not rely on Clegg for "without requiring disassociation"

Motivation to Combine: Chincholi + Clegg

- Chincholi discloses "evaluating" data characteristics and selecting bandwidth portions using that information

> "The OMMA layer may receive a quality of service (QoS) of the first IP packet and a QoS of the second IP packet. The resources on the first RAT and on the second RAT may be requested based on at least one of the feedback information relating to the first RAT, the feedback information relating to the second RAT, the QoS of the first IP packet, and the QoS of the second IP packet. The resources may be requested on the first RAT and on the second RAT using one or more of an A 1 interface and an A2 interface. Although described with reference to two IP packets and two RATs, MAC resource reservation may be performed by the OMMA layer for any number of IP packets of an IP flow and for any number of different RATs."

Ex. 1005 (Chincholi) at [0260]; 564 Pet. at 37

Motivation to Combine: Chincholi + Clegg

- Clegg also teaches evaluating interference levels of each carrier's frequency channel, and selecting bandwidth portions

"Where interference is determined (by way of measurement or evaluation) to be too high or above a threshold amount, the subcarriers suffering an unduly high amount of interference may be "notched out" on a carrier-by-carrier basis."

Ex. 1009 (Clegg) at 7:15-19; 564 Pet. at 39

"In doing so, an IEEE 802.11 device utilizes an ultra-wideband tuner to evaluate the entire available spectrum between several communication bands (e.g., the 2.4 GHz and 5 GHz bands), and then take advantage of the OFDM protocol to cancel interference on a carrier-by-carrier or cluster-by-cluster basis."

Ex. 1009 (Clegg) at 3:60-65; 976 Pet. at 40

"In doing so, the AP and UE search across 1) available bands (e.g., the 2.4 GHz, 5 GHZ, and/or 60 GHz bands), and 2) sub-channels within each band, and measure interference on a carrier-by-carrier basis across those bands and sub-channels. Either of the AP and UE may select a cluster of carriers for communication"

Ex. 1009 (Clegg) 4:5-9; 564 Pet. at 40

Motivation to Combine: Chincholi + Clegg

- A POSITA would have a motivation to combine Chincholi with Clegg

> "A POSITA would have been motivated to incorporate the teachings of Clegg to improve the Chincholi system by allowing it to more flexibly and efficiently utilize available bandwidth channels that may experience carrier-specific interference within the channels. Chincholi already teaches dynamic allocation of contiguous or non-contiguous channels, and Clegg merely provides additional detail on how to mitigate carrier-specific interference within any given channel. The teachings of Clegg are complementary to Chincholi, and a POSITA would have recognized that Clegg's teachings could be easily implemented into Chincholi without technical challenge."

564 Ex. 1002 (Almeroth Decl.) at ¶80; 564 Pet. 15

Motivation to Combine: Chincholi + Clegg

- **PO:** Combination requires extensive reworking because of Clegg's "ultra-wideband tuner" **564 POR 60**
- **Incorrect:** The Petitions do not propose using Clegg's "ultra-wideband tuner," as Chincholi already discloses 802.11 transceivers

"My opinion does not require replacing Chincholi's transceivers with Clegg's ultra-wideband tuner. The relevant teachings of Clegg for purposes of the combination are Clegg's carrier-level interference-mitigation teachings—measuring interference on a carrier-by-carrier basis, avoiding or notching out interfered carriers, and selecting a suitable cluster of carriers based on those measurements. A POSITA would have understood those teachings could be applied within the channels and RAT resources already monitored and allocated by Chincholi's OMMA architecture."

564 Ex. 1026 (Almeroth Supp. Decl.) at ¶102; 564 Pet. 26

"The NT 201 may operate using one flavor of the 802.1 1 system (e.g., 1 la/b/g/n) at any given time over a specific band (e.g., 2.4GHz or 5GHz) when communicating with a WTRU."

Ex. 1005 (Chincholi) at [0121]; 564 Reply at 18

Motivation to Combine: Chincholi + Clegg

- **PO:** Clegg does not teach lack of disassociation, i.e. "make before break" **564 POR 61**

- **Incorrect:** The Petitions do not rely on Clegg for "without requiring disassociation"
  - The Petitions only rely on Clegg for additional feedback inputs for evaluating the channel

"That criticism does not change my opinions because I did not rely on Clegg or Choi to supply the "without requiring disassociation" limitation. As discussed above, Chincholi itself discloses dynamic RAT switching and packet duplication across RATs during switching, which teaches transmission without requiring disassociation."

564 Ex. 1026 (Almeroth Supp. Decl.) at ¶113; 564 Reply 17

"A POSITA would have been motivated to incorporate the teachings of Clegg to improve the Chincholi system by allowing it to more flexibly and efficiently utilize available bandwidth channels that may experience carrier-specific interference within the channels."

564 Ex. 1002 (Almeroth Decl.) at ¶80; 564 Pet. 15

Motivation to Combine Chincholi and Choi

Motivation to Combine: Chincholi + Choi

IPR No.	Patent No.	Combination
IPR2025-01208	11,974,143	Chincholi, Riggert (+Choi (Ground 2))
IPR2025-01209	11,856,414	Chincholi, Riggert (+Choi (Ground 2))
PGR2025-00069	12,250,564	Chincholi, Choi, Clegg

Motivation to Combine: Chincholi + Choi

- **PO:**
  - Choi does not teach “without requiring disassociation”
  - Choi does not teach “does not prevent”

- PO is ***incorrect***:
  - The petitions do not propose using Choi for “disassociation” or “does not prevent”
  - Petitions rely on Chincholi for those limitations

Motivation to Combine: Chincholi + Choi

- Chincholi discloses "evaluating" data characteristics and selecting bandwidth portions using that information

> "The OMMA layer may receive a quality of service (QoS) of the first IP packet and a QoS of the second IP packet. The resources on the first RAT and on the second RAT may be requested based on at least one of the feedback information relating to the first RAT, the feedback information relating to the second RAT, the QoS of the first IP packet, and the QoS of the second IP packet. The resources may be requested on the first RAT and on the second RAT using one or more of an A 1 interface and an A2 interface. Although described with reference to two IP packets and two RATs, MAC resource reservation may be performed by the OMMA layer for any number of IP packets of an IP flow and for any number of different RATs."

Ex. 1005 (Chincholi) at [0260]; 564 Pet. at 37

Motivation to Combine: Chincholi + Choi

- Choi also teaches evaluating channel quality, and selecting bandwidth frequencies based on that

"The monitoring of channels 100 includes three substeps of (1) channel measurement by AP, (2) request for channel measurement by AP; and, (3) measurement report by STAs."

Ex. 1016 (Choi) at 4:19-22; 564 Pet. 35-36

"Hence, prior to making a switch to the best wireless link, the AP needs to know the status of the current and other channels as well as the presence of other licensed operators, by detecting the channel conditions directly or by requesting the channel conditions from the associated STAs."

Ex. 1016 (Choi) at 4:34-39; 564 Pet. 35-36

Motivation to Combine: Chincholi + Choi

- A POSITA would have a motivation to combine Chincholi with Choi

> "A POSITA would have been motivated to incorporate the teachings of Choi to improve the Chincholi system by allowing it to more flexibly and efficiently utilize available bandwidth channels to minimize mutual interference. Chincholi already teaches identifying available bandwidth channels for communication, receiving feedback information from each RAT, evaluating the identified channel availabilities, and switching from one RAT to another due to superior data transfer characteristics. Choi merely provides additional detail on how to apply this similar methodology to selecting and switching frequency channels. The teachings of Choi are complementary to Chincholi, and a POSITA would have recognized that Choi's teachings could be implemented into Chincholi without technical challenge and with a reasonable expectation of success."

564 Ex. 1002 (Almeroth Decl.) at ¶81; 564 Pet. 15

Motivation to Combine: Chincholi + Choi

- **PO:** Choi does not teach lack of disassociation, i.e. "make before break" **564 POR 63-64**

- **Incorrect:** The Petitions do not rely on Choi for "without requiring disassociation"
  - The Petitions only rely on Choi for additional feedback inputs for evaluating the channel

"That criticism does not change my opinions because I did not rely on Clegg or Choi to supply the "without requiring disassociation" limitation. As discussed above, Chincholi itself discloses dynamic RAT switching and packet duplication across RATs during switching, which teaches transmission without requiring disassociation."

564 Ex. 1026 (Almeroth Supp. Decl.) at ¶113; 564 Reply 17

"A POSITA would have further understood that Chincholi's monitoring and response techniques could be enhanced by the teachings of Choi. Choi teaches a dynamic frequency selection techniques for addressing interference and reduced quality of WLAN networks by measuring frequency channel characteristics and selecting the frequency channel with minimum interference signal level."

564 Ex. 1002 (Almeroth Decl.) at ¶81; 564 Pet. 15

Motivation to Combine: Chincholi + Choi

- **PO:** Choi teaches using single-user techniques, not multi-user techniques **564 POR 64**

- **Incorrect:** The Petitions do not rely on Choi for "does not prevent," i.e. allowing multiple users
  - The Petitions only rely on Choi for additional feedback inputs for evaluating the channel

"That criticism does not change my opinions because I did not rely on Clegg or Choi to supply the "without requiring disassociation" limitation. As discussed above, Chincholi itself discloses dynamic RAT switching and packet duplication across RATs during switching, which teaches transmission without requiring disassociation."

564 Ex. 1026 (Almeroth Supp. Decl.) at ¶113

"A POSITA would have further understood that Chincholi's monitoring and response techniques could be enhanced by the teachings of Choi. Choi teaches a dynamic frequency selection techniques for addressing interference and reduced quality of WLAN networks by measuring frequency channel characteristics and selecting the frequency channel with minimum interference signal level."

564 Ex. 1002 (Almeroth Decl.) at ¶81; 564 Pet. 15

Motivation to Combine: Chincholi + Choi

- **PO:** Petitions bring in an additional reference Wang into the combination 564 POR 62
- **Incorrect:** Wang was merely used to show avoiding disassociation was desirable

> "For example, in the field of 802.11 systems—where each associated terminal is assigned a unique association identifier ("AID")—it was well-known that avoiding disassociation after initial association was desirable, as repeatedly re-forming associations was inefficient and disruptive. (EX1008 ("Wang") at 24:42-43 ("This approach is undesirable, can be blunt and can disrupt the on-going services (e.g., requires disassociation), at 24:57-62 ("The lack of update/change of the AID values . . . after an initial AID assignment is inherently inflexible and can prevent the realization power saving, among other considerations, that an update/change of the AID values can provide.")"

564 Ex. 1002 (Almeroth Decl.) at ¶129; 564 Pet. 40

Samsung Electronics Co., Ltd. et al. v. XiFi Networks R&D, Inc.

Petitioners' Demonstratives

Hearing: October 7th and 8th, 2026

Summary of Section 101/112 Disputed Issues

Issue	PGR-00067	PGR-00068	PGR-00069
§101 Ineligibility	X	X	X
§112 written description: “transparent”	X	X	X
§112 written description: “better” / “compar[e]” “data characteristics”	X	X	X
§112 written description: “resource monitoring interface”	X	X	X
§112 written description: “different bands of frequencies”	X	X	X
§112 written description: “association”	X	X	X
§112 written description: “without disassociation”			X
§112 written description: “do not prevent”			X
§112 indefiniteness: “[partially/substantially] simultaneously”	X	X	X
§112 indefiniteness: “partially satisfy”	X	X	
§112 indefiniteness: “better than”			X
§112 indefiniteness: “received by first transceiver”			X

Section 101 Ineligibility
(‘546, ‘756, ‘198 patents)

Section 101 Patent Ineligibility

- **Step 1 (Abstract Idea):**
  - All claims are directed to **evaluating and selecting available communication resources**

- **Step 2 (Lack of inventive concept):**
  - All claims recite conventional networking components
  - The claims are directed to the function of the "processing interface"

- Patent Owner largely focuses on the ***unclaimed*** location of the "processing interface"

Section 101 Patent Ineligibility: Step 1

"Because all inventions embody, use, reflect, rest upon, or apply laws of nature, natural phenomena, or abstract ideas, we must decide whether that patent-ineligible concept is what the claim is directed to. To do so, we evaluate the focus of the claimed advanced over the prior art to determine if the claim's character as a whole is directed to excluded subject matter."

PersonalWeb Techs. LLC v. Google LLC, 8 F.4th 1310, 1315 (Fed. Cir. 2021) (citations omitted)

"Ericsson misstates the role of the specification, which cannot be used to import details from the specification if those details are not claimed. Rather, any reliance on the specification the § 101 analysis must always yield to the claim language."

Ericsson v. TCL Communication Tech. Holdings, 995 F.3d 1317, 1328-29 (Fed. Cir. 2020) (citations omitted)

Section 101 Patent Ineligibility: Step 1

- The claims are directed to the abstract concept of a processing interface **evaluating and selecting available communication resources**

1. A wireless networking device, comprising:

a processing interface that is connected to an application interface, the application interface being associated with a first application, the first application providing, when the wireless networking device is being used, a first data stream and having a first wireless bandwidth requirement;

first and second actual MAC interfaces connected to the processing interface;

first and second actual PHY interfaces respectively connected to the first and second actual MAC interfaces;

first and second wireless transceivers respectively associated with the first and second actual PHY interfaces, wherein each of the first and second wireless transceivers is suitable for use in a wireless local area network, and the first and second wireless transceivers, respectively, (i) have a first and second bandwidth availability up to first and second actual bandwidths, and (ii) are adapted to emit radio waves in first and second different bands of frequencies;

at least one virtual MAC interface and at least one resource monitoring interface formed in the processing interface that, during operation of the wireless networking device, feeds information regarding the bandwidth availabilities of the first and second wireless transceivers back to the at least one virtual MAC interface;

Section 101 Patent Ineligibility: Step 1

- The claims are directed to the abstract concept of a processing interface **evaluating and selecting available communication resources**

wherein the processing interface is configured to, when the wireless networking device is being used, and in a manner transparent to any layer of the wireless networking device above the processing interface,

(a) request or create (i) a first association between a recipient and the first actual MAC and PHY interfaces and (ii) a second association between the recipient and the second actual MAC and PHY interfaces,

(b) identify at least one first and second portions of the first actual bandwidth of the first wireless transceiver, each one of the first and second identified bandwidth portions each having a set of given resources,

(c) evaluate the data transfer characteristics of the given resources of both the first and second identified bandwidth portions,

(d) if the data transfer characteristics of the first identified bandwidth portion are better than those of the second identified bandwidth portion, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the first identified bandwidth portion that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

(e) if the data transfer characteristics of the second identified bandwidth portion are better than those of the first identified bandwidth portion, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the second identified bandwidth portion that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

wherein, when the wireless networking is being used, the wireless networking device's utilization of the first and second identified bandwidth portions do not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the first wireless transceiver for data transmission or reception purposes at the same time that the first or second identified bandwidth portions are being used for data transmission purposes.

Section 101 Patent Ineligibility: Step 1

- The claims are directed to the abstract concept of a processing interface **evaluating and selecting available communication resources**

Agreed Construction
"virtual MAC interface"
"a software- or logical-based interface that is separately addressable from the recited actual MAC interfaces and that obscures the recited actual MAC interfaces from higher protocol stack layers"

Agreed Construction
"transparent to any layer"
"in a manner where any protocol stack layer of the wireless networking device above the processing interface is unaware of the operation of the processing interface"

Section 101 Patent Ineligibility: Step 1

- The claims are directed to **functional results**

(c) evaluate the data transfer characteristics of the given resources of both the first and second identified bandwidth portions,

(d) if the data transfer characteristics of the first identified bandwidth portion are better than those of the second identified bandwidth portion, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the first identified bandwidth portion that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and



"[A] claim that merely describes an effect or result dissociated from any method by which it is accomplished is not directed to patent-eligible subject matter."

Apple, Inc. v. Ameranth, Inc., 842 F.3d 1229, 1244 (Fed. Cir. 2016)

Section 101 Patent Ineligibility: Step 1

- Patent Owner:

> "The title of the '564 patent is "Method and Apparatus for Processing Bandwidth Intensive Data Streams Using Virtual Media Access Control and Physical Layers." Consistent with that title, the inventions claimed in the '564 patent provide improved intelligent resource allocation and bandwidth utilization within wireless network systems by using a virtual MAC interface and a resource monitoring interface. EX1001, Abstract, 2:48-55, 2:60-3:3, 4:30-5:30, 12:25-30, Figs. 1-3. Key aspects of the invention of the '564 patent include the use of virtual MAC interface and resource monitoring interface to facilitate transparent bandwidth decision making, obscuring the addresses and operation of the actual MAC and PHY layers to the upper layers, as well as allowing a single transceiver's bandwidth to be shared among two separate users simultaneously. EX1001, Abstract, Fig. 1."

POR at 7-8

Section 101 Patent Ineligibility: Step 1

- Patent Owner:

> "The '564 patent discloses specific improvements to the functioning of wireless networking devices and the "insatiable demand for more bandwidth" by introducing an architecture that (1) determines wireless bandwidth demand from one or more applications, (2) defines virtual MAC and virtual PHY layers that determine available resources in the actual MAC and PHY layers, and (3) allocates available resources to satisfy the bandwidth demands of the one or more applications."

564 Surreply at 20

Section 101 Patent Ineligibility: Step 1

- Patent Owner's expert Dr. Akl:

"Immediately above the physical layer is the data link layer, whose function is to transform the raw data as transmitted by the physical layer into data frames that appear to the next higher layer (the network layer) as error-free."

Ex. 2017 (Akl Decl.) at ¶48

"A POSITA would understand that "virtual" means that which is not physical or tied to the physical world, but rather software-based, abstract, or logical."

Ex. 2017 (Akl Decl.) at ¶52

"[A] POSITA would understand that the processing interface of the '564 Patent must sit in layer 2 (or the data link layer) because components of the processing interface communicate directly with the physical layer (layer 1). See supra, ¶¶56, 64. A POSITA would also understand that the functions of the virtual MAC interface are quintessential layer 2 functions, such as the monitoring function of the ultra-streaming block that a POSITA would understand to be associated with layer 2."

Ex. 2017 (Akl Decl.) at ¶88

Section 101 Patent Ineligibility: Step 1

Two-way Media Ltd. v. Comcast Cable Comm'ns, LLC, 874 F.3d 1329 (Fed. Cir. 2017)

1. A method for transmitting message packets over a communications network comprising the steps of:

converting a plurality of streams of audio and/or visual information into a plurality of streams of addressed digital packets complying with the specifications of a network communication protocol,

for each stream, routing such stream to one or more users,

controlling the routing of the stream of packets in response to selection signals received from the users, and

monitoring the reception of packets by the users and accumulating records that indicate which streams of packets were received by which users, wherein at least one stream of Rackets comprises an audio and/or visual selection and the records that are accumulated indicate the time that a user starts receiving the audio and/or visual selection and the time that the user stops receiving the audio and/or visual selection.

"The claim requires the functional results of "converting," "routing," "controlling," "monitoring," and "accumulating records," but does not sufficiently describe how to achieve these results in a non-abstract way."

Id. at 1337

"Though Two-Way Media argues that its proposed claim constructions sufficiently tie the claims to particular scalable network architecture, the constructions recite only conventional computer components."

Id. at 1338

Section 101 Patent Ineligibility: Step 1

Rady v. Boston Consulting Groupd, Inc., 2024 WL 1298742 (Fed. Cir. 2024)

1. A network node comprising:
one or more processing devices;
a storage device, coupled to the one or more processing devices and storing instructions for execution by at least some of the one or more processing devices;
a communications subsystem, coupled to the one or more processing devices, to communicate with at least one or more other nodes of a peer-to-peer network; and
item analysis components coupled to the one or more processing devices, the item analysis components comprising at least one imaging device configured to determine spectral analysis data and 3D scan data from measurements generated by the item analysis components;
wherein the one or more processing devices operate to configure the network node to:

analyze an instance of a physical item using the item analysis components to determine a unique signature for the instance, the unique signature determined using 3D spatial mapping to define the unique signature from the spectral analysis data and 3D scan data generated by the item analysis components for the physical item;
determine, using the unique signature, whether the instance of the physical item is previously recorded to a blockchain maintained by the peer-to-peer network to provide item tracking and authentication services, comparing the unique signature generated by the network node to previously recorded unique signatures using 3D spatial analysis techniques, rotating in virtual space features of the physical item defined in the unique signature to determine a match with features defined in the previously recorded unique signatures; and
record the instance of the physical item to the blockchain in response to the determining whether the instance is previously recorded.

"Claim 1 requires identifying a physical item's unique pattern of physical imperfections, or "signature," and then recording that information to a blockchain if the object has not been previously registered. '250 patent col. 19 ll. 15–51. As we have often emphasized, however, claims directed to gathering and storing data, without more, are impermissibly abstract."

"As we have previously recognized, claims are not saved from abstraction merely because they recite components more specific than a generic computer."

Id. at *3

Section 101 Patent Ineligibility: Step 1

Ericsson v. TCL Comm'n Tech. Holdings, 955 F.3d 1317 (Fed. Cir. 2021)

1. A system for controlling access to a platform, the system comprising:

a platform having a software services component and an interface component, the interface component having at least one interface for providing access to the software services component for enabling application domain software to be installed, loaded, and run in the platform;

an access controller for controlling access to the software services component by a requesting application domain software via the at least one interface, the access controller comprising:

an interception module for receiving a request from the requesting application domain software to access the software services component;

and a decision entity for determining if the request should be granted wherein the decision entity is a security access manager, the security access manager holding access and permission policies; and

wherein the requesting application domain software is granted access to the software services component via the at least one interface if the request is granted.

"Based on the claim language, we conclude that claims 1 and 5 are directed to the abstract idea of controlling access to, or limiting permission to, resources. Although written in technical jargon, a close analysis of the claims reveals that they require nothing more than this abstract idea. …

Controlling access to resources is exactly the sort of process that "can be performed in the human mind, or by a human using a pen and paper," which we have repeatedly found unpatentable."

Id. at 1326-27

Section 101 Patent Ineligibility: Step 1

PersonalWeb Techs. LLC v. Google LLC, 8 F.4th 1310 (Fed. Cir. 2021)

24. A computer-implemented method implemented at least in part by hardware comprising one or more processors, the method comprising:

(a) using a processor, receiving at a first computer from a second computer, a request regarding a particular data item, said request including at least a content-dependent name for the particular data item, the content-dependent name being based, at least in part, on at least a function of the data in the particular data item, wherein the data used by the function to determine the content-dependent name comprises at least some of the contents of the particular data item, wherein the function that was used comprises a message digest function or a hash function, and wherein two identical data items will have the same content-dependent name; and

(b) in response to said request:

(i) causing the content-dependent name of the particular data item to be compared to a plurality of values;

(ii) hardware in combination with software determining whether or not access to the particular data item is unauthorized based on whether the content-dependent name of the particular data item corresponds to at least one of said plurality of values, and

(iii) based on said determining in step (ii), not allowing the particular data item to be provided to or accessed by the second computer if it is determined that access to the particular data item is not authorized.

"We therefore conclude that the claims are directed to the use of an algorithm-generated content-based identifier to perform the claimed data-management functions, which across the three patents include controlling access to data items (the '310 patent), retrieving and delivering copies of data items (the '280 patent), and marking copies of data items for deletion (the '662 patent)."

Id. at 1316

"The claims as a whole, then, are directed to a medley of mental processes that, taken together, amount only to a multistep mental process."

Id. at 1318

Section 101 Patent Ineligibility: Step 1

Intellectual Ventures I LLC v. Symantec Corp., 838 F.3d 1307 (Fed. Cir. 2016)

9. A method for identifying characteristics of data files, comprising:

receiving, on a processing system, file content identifiers for data files from a plurality of file content identifier generator agents, each agent provided on a source system and creating file content IDs using a mathematical algorithm, via a network;

determining, on the processing system, whether each received content identifier matches a characteristic of other identifiers; and

outputting, to at least one of the source systems responsive to a request from said source system, an indication of the characteristic of the data file based on said step of determining.

"We agree with the district court that receiving e-mail (and other data file) identifiers, characterizing e-mail based on the identifiers, and communicating the characterization—in other words, filtering files/e-mail—is an abstract idea."

Id. at 1313

"The patent merely applies a well-known idea using generic computers to the particular technological environment of the Internet."

Id. at 1314

Section 101 Patent Ineligibility: Step 1

- **Patent Owner:** The concrete improvement is bandwidth allocation decision-making while sitting at the MAC sublayer of layer 2, transparent to layers above

- **PO is incorrect:** Neither the claims or the specification require the virtual MAC interface to be located at any particular layer or sublayer

"The Court agrees with Samsung, and it need not delve deep into the parties' arguments to do so. The disputed language states nothing about the *source* of the information. Rather, it limits the information's *content*. To change the plain meaning of the claim language requires lexicography or disavowal, neither of which XiFi asserts. And even to the extent a skilled artisan would understand the disclosed embodiments as communicating information directly from the transceivers to the processing layer, that is not what XiFi claimed."

Ex. 1027 at 16; 564 Reply 20

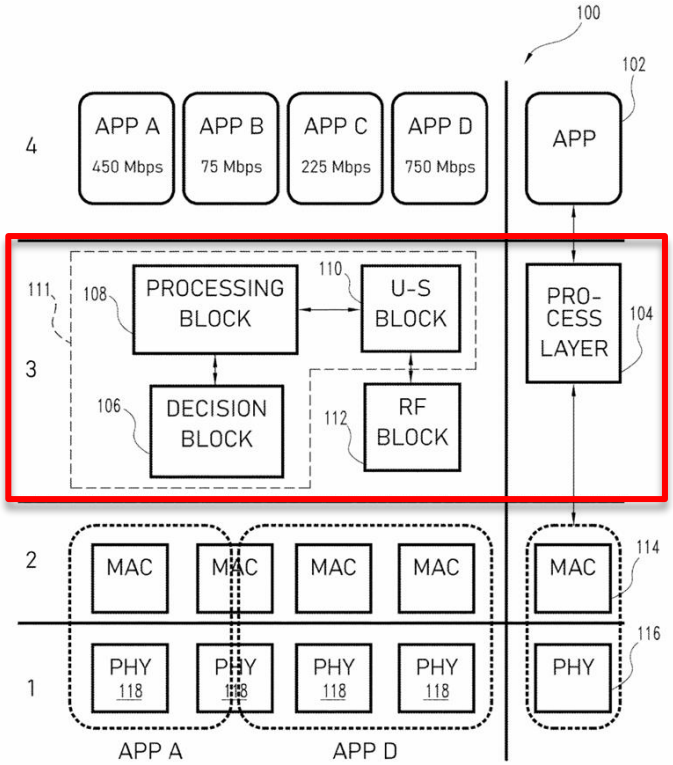


Fig. 1

EX1001 (564 patent) at Fig. 1

Section 101 Patent Ineligibility: Step 1

- **Patent Owner:** Virtual MAC/PHY layers are a technical improvement that allow simultaneous allocation of resources

- **PO is incorrect:** The claims only recite the desired results, not ***how*** to allocate the resources

(c) evaluate the data transfer characteristics of the given resources of both the first and second identified bandwidth portions,

(d) if the data transfer characteristics of the first identified bandwidth portion are better than those of the second identified bandwidth portion, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the first identified bandwidth portion that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

wherein, when the wireless networking is being used, the wireless networking device's utilization of the first and second identified bandwidth portions do not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the first wireless transceiver for data transmission or reception purposes at the same time that the first or second identified bandwidth portions are being used for data transmission purposes.



"[A] claim that merely describes an effect or result dissociated from any method by which it is accomplished is not directed to patent-eligible subject matter."

Apple, Inc. v. Ameranth, Inc., 842 F.3d 1229, 1244 (Fed. Cir. 2016)

Section 101 Patent Ineligibility: Step 1

- PO's cases are inapposite

***Enfish, LLC v. Microsoft Corp.*, 822 F.3d 1327 (Fed. Cir. 2016)**

17. A data storage and retrieval system for a computer memory, comprising:

means for configuring said memory according to a logical table, said logical table including:

a plurality of logical rows, each said logical row including an object identification number (OID) to identify each said logical row, each said logical row corresponding to a record of information;

a plurality of logical columns intersecting said plurality of logical rows to define a plurality of logical cells, each said logical column including an OID to identify each said logical column; and

means for indexing data stored in said table.

"Here, the claims are not simply directed to *any* form of storing tabular data, but instead are specifically directed to a *self-referential* table for a computer database. For claim 17, this is reflected in step three of the "means for configuring" algorithm described above."

Id. at 1337

"In sum, the self-referential table recited in the claims on appeal is a specific type of data structure designed to improve the way a computer stores and retrieves data in memory."

Id. at 1339

Section 101 Patent Ineligibility: Step 1

- PO's cases are inapposite



"InvestPic also argues that the '291 patent's claims are similar to others we have concluded were patentable at the first stage of the *Alice* inquiry, specifically the claims in *Enfish* and *BASCOM*. In those cases, claims were patent-eligible because they were directed to improvements **in the way** computers and networks carry out their basic functions."

SAP Am., Inc. v. InvestPic, LLC, 898 F.3d 1161, 1167 (Fed. Cir. 2018); 564 Pet. 76

Section 101 Patent Ineligibility: Step 1

- PO's cases are inapposite

Contour IP Holding LLC v. GoPro, Inc., 113 F.4th 1373 (Fed. Cir. 2024)

a camera processor configured to:
receive the video image data directly or indirectly from the image sensor,
generate from the video image data a first image data stream and a second image data stream, wherein the second image data stream is a higher quality than the first image data stream,
cause the wireless connection protocol device to send the first image data stream directly to the personal portable computing device for display on a display of the personal portable computing device, wherein the personal portable computing device generates the control signals for the video camera, and wherein the control signals comprise at least one of a frame alignment, multi-camera synchronization, remote file access, and a resolution setting, and at least one of a lighting setting, a color setting, and an audio setting,
receive the control signals from the personal portable computing device, and
adjust one or more settings of the video camera based at least in part on at least a portion of the control signals received from the personal portable computing device.

"Importantly, the district court construed "generate" in representative claim 11 to require recording multiple video streams 'in parallel.'"

Id. at 1379

"[T]he district court's conclusion that the claims were "directed to a result or effect that itself is the abstract idea" disregards the disclosed technological means for obtaining a technological result."

Id. at 1380

Section 101 Patent Ineligibility: Step 1

- PO's cases are inapposite

Packet Intelligence LLC v. Netscout Systems, Inc., 965 F.3d 1299 (Fed. Cir. 2020)

19. A packet monitor for examining packets passing through a connection point on a computer network, each packets conforming to one or more protocols, the monitor comprising:

(a) a packet acquisition device coupled to the connection point and configured to receive packets passing through the connection point;

(b) an input buffer memory coupled to and configured to accept a packet from the packet acquisition device;

(c) a parser subsystem coupled to the input buffer memory and including a slicer, the parsing subsystem configured to extract selected portions of the accepted packet and to output a parser record containing the selected portions;

(d) a memory for storing a database comprising none or more flow-entries for previously encountered conversational flows, each flow-entry identified by identifying information stored in the flow-entry;

(e) a lookup engine coupled to the output of the parser subsystem and to the flow-entry memory and configured to lookup whether the particular packet whose parser record is output by the parser subsystem has a matching flow-entry, the looking up using at least some of the selected packet portions and determining if the packet is of an existing flow; and

(f) a flow insertion engine coupled to the flow-entry memory and to the lookup engine and configured to create a flow-entry in the flow-entry database, the flow-entry including identifying information for future packets to be identified with the new flow-entry, the lookup engine configured such that if the packet is of an existing flow, the monitor classifies the packet as belonging to the found existing flow; and if the packet is of a new flow, the flow insertion engine stores a new flow-entry for the new flow in the flow-entry database, including identifying information for future packets to be identified with the new flow-entry,

wherein the operation of the parser subsystem depends on one or more of the protocols to which the packet conforms.

"The claim solves a technological problem by identifying and refining a conversational flow such that different connection flows can be associated with each other and ultimately with an underlying application or protocol. The claims detail how this is achieved in several steps."

Id. at 1309

Section 101 Patent Ineligibility: Step 1

- PO's cases are inapposite

***Uniloc USA, Inc. v. LG Electronics USA, Inc.*, 957 F.3d 1303 (Fed. Cir. 2020)**

2. A primary station for use in a communications system comprising at least one secondary station, wherein means are provided for broadcasting a series of inquiry messages, each in the form of a plurality of predetermined data fields arranged according to a first communications protocol, and for adding to each inquiry message prior to transmission an additional data field for polling at least one secondary station.

"The claims at issue do not merely recite generalized steps to be performed on a computer using conventional computer activity. Instead, they are directed to "adding to each inquiry message prior to transmission an additional data field for polling at least one secondary station." *See, e.g.*, '049 patent at Claim 2. And this change in the manner of transmitting data results in reduced response time by peripheral devices which are part of the claimed system."

Id. at 1308

Section 101 Patent Ineligibility: Step 1

- PO's cases are inapposite

***Mentone Solutions LLC v. Digi Int'l Inc.*, 2021 WL 5291802 (Fed. Cir. 2021)**

5. A multiple access communication method in a mobile station, comprising the steps of:

receiving an assignment of at least a first PDCH (packet data channel) and a second PDCH;

monitoring an assigned PDCH to detect a USF; and

transmitting on an assigned PDCH corresponding to the USF,

wherein (i) if shifted USF operation is not used then a first assigned PDCH is monitored to detect a USF corresponding to the first assigned PDCH and (ii) if the shifted USF operation is used then a second assigned PDCH is monitored to detect the USF corresponding to the first assigned PDCH and a USF corresponding to the second assigned PDCH.

"The claim does not merely recite generalized steps to be performed on a computer. Nor does it recite data manipulation on a generic computer as Appellees argue. Appellees' Br. 12. Claim 5 recites a particular method of breaking the fixed relationship between the timing of a downlink USF and subsequent uplink transmission: the mobile station receives an assignment of two distinct PDCHs, and, if the shifted USF operation is used, it monitors the second PDCH for USFs corresponding to the first and second PDCH and transmits on those PDCHs accordingly."

Id. at *4

Section 101 Patent Ineligibility: Step 1

- PO's cases are inapposite

***SRI Int'l, Inc. v. Cisco Systems, Inc.*, 930 F.3d 1295 (Fed. Cir. 2019)**

1. A computer-automated method of hierarchical event monitoring and analysis within an enterprise network comprising:

deploying a plurality of network monitors in the enterprise network;

detecting, by the network monitors, suspicious network activity based on analysis of network traffic data selected from one or more of the following categories: {network packet data transfer commands, network packet data transfer errors, network packet data volume, network connection requests, network connection denials, error codes included in a network packet, network connection acknowledgements, and network packets indicative of well-known network-service protocols};

generating, by the monitors, reports of said suspicious activity; and

automatically receiving and integrating the reports of suspicious activity, by one or more hierarchical monitors.

"The claims are directed to using a specific technique—using a plurality of network monitors that each analyze specific types of data on the network and integrating reports from the monitors—to solve a technological problem arising in computer networks: identifying hackers or potential intruders into the network."

Id. at 1303

Section 101 Patent Ineligibility: Step 2

- **No inventive concept:** conventional networking components performing conventional functions

1. A wireless networking device, comprising:

a processing interface that is connected to an application interface, the application interface being associated with a first application, the first application providing, when the wireless networking device is being used, a first data stream and having a first wireless bandwidth requirement;

first and second actual MAC interfaces connected to the processing interface;

first and second actual PHY interfaces respectively connected to the first and second actual MAC interfaces;

first and second wireless transceivers respectively associated with the first and second actual PHY interfaces, wherein each of the first and second wireless transceivers is suitable for use in a wireless local area network, and the first and second wireless transceivers, respectively, (i) have a first and second bandwidth availability up to first and second actual bandwidths, and (ii) are adapted to emit radio waves in first and second different bands of frequencies;

at least one virtual MAC interface and at least one resource monitoring interface formed in the processing interface that, during operation of the wireless networking device, feeds information regarding the bandwidth availabilities of the first and second wireless transceivers back to the at least one virtual MAC interface;

Section 101 Patent Ineligibility: Step 2

- **No inventive concept:** conventional networking components performing conventional functions

wherein the processing interface is configured to, when the wireless networking device is being used, and in a manner transparent to any layer of the wireless networking device above the processing interface,

(a) request or create (i) a first association between a recipient and the first actual MAC and PHY interfaces and (ii) a second association between the recipient and the second actual MAC and PHY interfaces,

(b) identify at least one first and second portions of the first actual bandwidth of the first wireless transceiver, each one of the first and second identified bandwidth portions each having a set of given resources,

(c) evaluate the data transfer characteristics of the given resources of both the first and second identified bandwidth portions,

(d) if the data transfer characteristics of the first identified bandwidth portion are better than those of the second identified bandwidth portion, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the first identified bandwidth portion that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

(e) if the data transfer characteristics of the second identified bandwidth portion are better than those of the first identified bandwidth portion, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the second identified bandwidth portion that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

wherein, when the wireless networking is being used, the wireless networking device's utilization of the first and second identified bandwidth portions do not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the first wireless transceiver for data transmission or reception purposes at the same time that the first or second identified bandwidth portions are being used for data transmission purposes.

Section 101 Patent Ineligibility: Step 2

- **No inventive concept:** conventional networking components performing conventional functions

> "By employing linear and/or radial wireless access system architectures. and configuring available wireless transceiver resources optimally within each node, a given wireless may be accessed with greater bandwidth and more efficiently."

Ex. 1001 (564 patent) at 10:52-56; 564 Pet. 81-82

Section 101 Patent Ineligibility: Step 2

- Patent Owner's expert Dr. Akl:

> "[A] POSITA would understand that the processing interface of the '564 Patent must sit in layer 2 (or the data link layer) because components of the processing interface communicate directly with the physical layer (layer 1). See supra, ¶¶56, 64. A POSITA would also understand that the functions of the virtual MAC interface are quintessential layer 2 functions, such as the monitoring function of the ultra-streaming block that a POSITA would understand to be associated with layer 2."

Ex. 2017 (Akl Decl.) at ¶88

Section 101 Patent Ineligibility: Step 2

- **Patent Owner:** The inventive concept is bandwidth allocation decision-making while sitting at the MAC sublayer of layer 2, transparent to layers above

- **PO is incorrect:** Neither the claims or the specification require the virtual MAC interface to be located at any particular layer or sublayer

"The Court agrees with Samsung, and it need not delve deep into the parties' arguments to do so. The disputed language states nothing about the *source* of the information. Rather, it limits the information's *content*. To change the plain meaning of the claim language requires lexicography or disavowal, neither of which XiFi asserts. And even to the extent a skilled artisan would understand the disclosed embodiments as communicating information directly from the transceivers to the processing layer, that is not what XiFi claimed."

Ex. 1027 at 16; 564 Reply 22

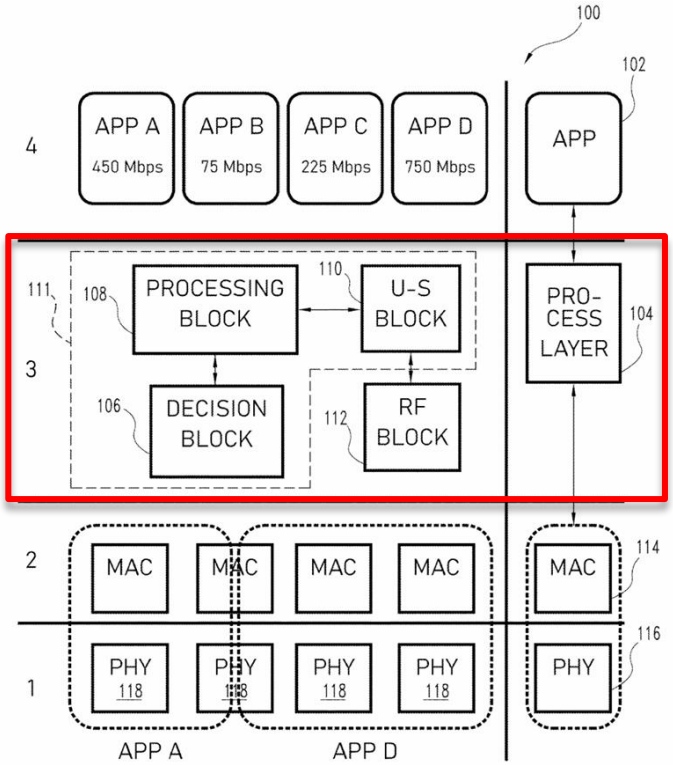


Fig. 1

EX1001 (564 patent) at Fig. 1

Section 101 Patent Ineligibility: Step 2

- **Patent Owner:** Inventive concept is virtual MAC/PHY layers that allow simultaneous allocation of resources **Surreply 24**

- **PO is incorrect:** The claims only recite the desired results, not ***how*** to allocate the resources

(c) evaluate the data transfer characteristics of the given resources of both the first and second identified bandwidth portions,

(d) if the data transfer characteristics of the first identified bandwidth portion are better than those of the second identified bandwidth portion, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the first identified bandwidth portion that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

wherein, when the wireless networking is being used, the wireless networking device's utilization of the first and second identified bandwidth portions do not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the first wireless transceiver for data transmission or reception purposes at the same time that the first or second identified bandwidth portions are being used for data transmission purposes.



"The claims at issue do not require any nonconventional computer, network, or display components, or even a non-conventional and non-generic arrangement of known, conventional pieces, but merely call for performance of the claimed information collection, analysis, and display functions on a set of generic computer components and display devices."

Electric Power Group, LLC v. Alstom SA., 830 F.3d 1350, 1355-56 (Fed. Cir. 2016)

Section 112 Lack of Written Description: “transparent” (‘546, ‘756, ‘198 patents)

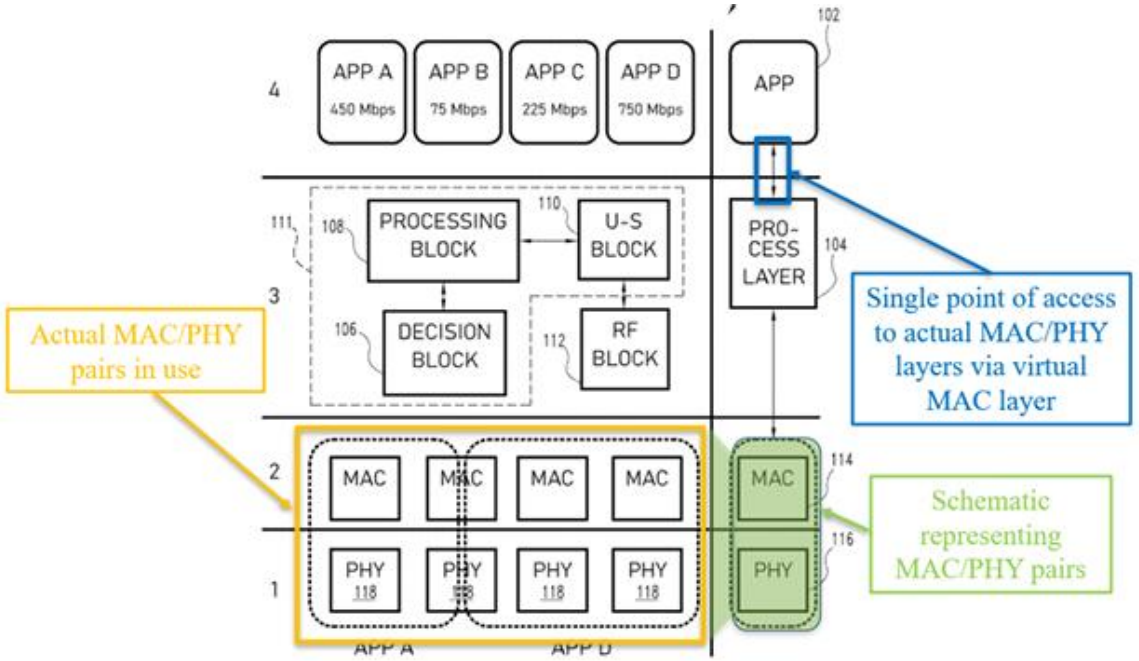
Lack of Written Description: “transparent to any layer ... above"

Agreed Construction
“transparent to any layer”
“in a manner where any protocol stack layer of the wireless networking device above the processing interface is unaware of the operation of the processing interface”

- The specification does not mention the word “transparent”
- Applicant did not cite to anything in the specification in support of its amendment adding “transparent”

Lack of Written Description: “transparent to any layer ... above"

- PO’s ***only*** citation to the specification is Figure 1 **POR 77**



- A “single point of access” does not actually or inherently disclose that the upper layers are “unaware” of the operation of the process layer
- Figure 1 and specification only describe the application layer, not other layers like the network and transport layers

Lack of Written Description: “transparent to any layer ... above"

- PO’s expert Dr. Akl

> “Further, as described above, the ’564 Patent recites transparent operations that are the result of the processing interface (and its components, including the virtual MAC interface and the resource monitoring interface) being part of the MAC sublayer of the data link layer.”

Ex. 2017 (Akl Decl.) at ¶125; Reply 14

Section 112 Lack of Written Description:

“better than” (‘564 patent)
“comparison of the evaluated data transfer characteristics” (‘756, ‘198 patents)

Lack of Written Description: “data transfer characteristics” “better than”

Limitations
‘564 patent: “if the data transfer characteristics of the *first* identified bandwidth **portion** are **better than** those of the *second* identified bandwidth **portion**” “if the data transfer characteristics of the *second* identified bandwidth **portion** are **better than** those of the *first* identified bandwidth **portion**”
‘756 and ‘198 patents: “based upon a comparison of the evaluated data transfer characteristics”

- The ‘546 claims require determining whether “data transfer characteristics” of a first or second bandwidth portion are **better**
- The ‘756 and ‘198 claims require a **comparison** of the data transfer characteristics of the first and second bandwidth portions

- The specification does not mention “data transfer characteristics” or how to **compare** them to decide which portion’s characteristics are **better**

Lack of Written Description: "data transfer characteristics" "better than"

- No dispute that "data transfers" disclosures fail to disclose comparisons POR 78-79

"The transmitter couples to the programmable storage and transmits data along a wireless link during a first portion of a programmed data transfer cycle."

Ex. 1001 (564 patent) at 3:7-12; Pet. 88

"The individual applications, for example, may have different peak bandwidth requirements in terms of data transfer rates."

Ex. 1001 (564 patent) at 3:21-23; Pet. 88

"The actual PHY layer 116 may include multiple transceiver resources corresponding to multiple radios, each with an actual data transfer capability, or bandwidth."

Ex. 1001 (564 patent) at 3:3:66; Pet. 88

"FIG. 6 illustrates one embodiment of the wireless networking system, described above, utilizing the variable duplex link to optimize uplink (transmit) and downlink (receive) data transfer efficiency for a given application."

Ex. 1001 (564 patent) at 5:50-51; Pet. 88

"Additionally, by selectively employing a variable duplex link, data transfers may be further optimized through finer control of link transmit and receive times."

Ex. 1001 (564 patent) at 6:9-11; Pet. 88

Lack of Written Description: "data transfer characteristics" "better than"

- PO's citations do not discuss characteristics related to evaluating bandwidth ***portions*** POR 78-79

"Should a given resource be unavailable, such as through insufficient bandwidth or having an existing assignment, a replacement resource may be identified and assigned."

Ex. 1001 (564 patent) at 5:1-8; POR at 78

"By employing a plurality of transceivers at each of the nodes that run the Ultra Streaming engine to allocate their available resources, either at initialization as configurable, or while in operation periodically, or dynamically in random demand while in operation, the most efficient path for wireless access is accomplished. This results in increased range and coverage for a given wireless network, and it's Internet access."

Ex. 1001 (564 patent) at 9:21-28; POR at 78

"Thus, with communication links established from the Internet to radio A1, to radio A2, to radio B1 to radio B2 to radio C1 and to radio C2, the user U3 is able to access the Internet wirelessly even though the distance between the user U3 to the first wireless access point A1 exceeds the coverage or range of radio A1."

Ex. 1001 (564 patent) at 7:40-46; POR at 78

"Should a given resource be unavailable, such as through insufficient bandwidth or having an existing assignment, a replacement resource may be identified and assigned."

Ex. 1001 (564 patent) at 5:1-8; POR at 78

Section 112 Lack of Written Description: “resource monitoring interface” (‘546, ‘756, ‘198 patents)

Lack of Written Description: "resource monitoring interface"

Limitation
"**resource monitoring interface** formed in the processing interface that … feeds information regarding bandwidth availabilities … back to the at least one virtual MAC interface"

- The specification does not mention or describe a "resource monitoring interface"
- The specification discloses a "virtual PHY layer" formed by "RF block 112," a "resource monitoring interface" is broader and not described

> "For one embodiment, the RF block(s) communicate directly with the ultra-streaming block about actual resource availability, and the ultra-streaming block sends the information back to the decision block in the virtual MAC layer."

Ex. 1001 (564 patent) at 4:54-56; Pet. 89

Lack of Written Description: "resource monitoring interface"

- Petitioner's expert Dr. Almeroth:

> "The '564 specification nowhere describes a resource monitoring interface. While the specification describes a virtual PHY layer that is formed by RF block 112 (3:51), which communicates with the ultra-streaming block about actual resource availability (4:54-56), a generic resource monitoring interface is a broader element that is not supported by mere description of virtual PHY layers."

Ex. 1002 (Almeroth Decl.) at ¶217; Pet. 89

- Claim 7 of '564 patent:

> **7**. The wireless networking device of claim **1**, wherein the resource monitoring interface includes an RF block.

Lack of Written Description: "resource monitoring interface"

- **PO:** The RF block and virtual PHY layers can be programmed to perform desired tasks and not others

- But specification does not disclose what those other tasks would be

> "Those disclosures do not identify a generic "resource monitoring interface" or describe the broader resource monitoring interface now claimed. They describe narrower RF-block and virtual PHY functionality."

Ex. 1026 (Almeroth Supp. Decl.) at ¶120; Reply 24

Section 112 Lack of Written Description: “different bands of frequencies” (‘546, ‘756, ‘198 patents)

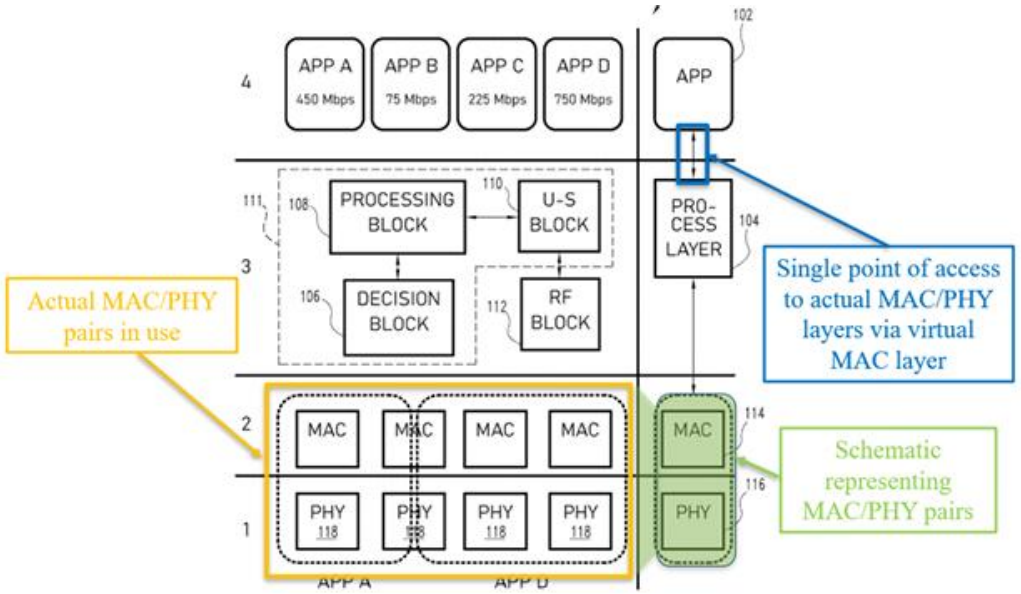
Lack of Written Description: “different bands of frequencies”

Limitation
“first and second wireless transceivers, respectively … are adapted to emit radio waves in first and second **different bands of frequencies**”

- The specification does not describe different transceivers operating on different frequency bands
  - Neither frequency bands or frequency allocation are mentioned

Lack of Written Description: “different bands of frequencies”

- **PO:**
  - A POSITA would know that Wi-Fi radios emit on different frequency bands, e.g. 2.4 and 5 GHz
  - Fig. 1 depicts multiple radios



- Fig. 1 does not depict multiple radios, nor imply simultaneous use of different bands
- PO’s complaint alleges inventor was frustrated by Wi-Fi’s using “***only one channel or bands*** (then, either 2.4 or 5 GHz) at a time”

Section 112 Lack of Written Description: “association” (‘546, ‘756, ‘198 patents)

Lack of Written Description: "association"

Limitation
"request or create … a [first/second] association between a recipient and the [first/second] actual MAC and PHY interfaces"

- The specification does not describe associations between a recipient and multiple MAC/PHY interfaces
- PO claims simultaneous association was the novelty of the patents, and not within the knowledge of a POSITA:

> "Prior to the XiFi Patents, application data transmitted over a Wi-Fi network was confined to a single band, and any switch to another band required that the association between a transmitter and a receiver on one band be broken before a new association on a different band could be made, i.e., "break before make.""

EX1018 (Complaint) at ¶34; Pet. 93-94

Lack of Written Description: "association"

- **PO:** "association" merely means two components in radio range and connected to each other
  POR 82
  - And the "recipient" is the receiver of the data in a data transmission

- **Incorrect:**
  - Nothing in the claims or specification indicates the recipient is connected to ***multiple*** MAC/PHY resources
  - PO's expert Dr. Akl:

> "To transmit data over a network, there needs to be an association between the transmitter and receiver of the data. In prior art Wi-Fi networks, when a decision was made to switch from one transmitter/receiver operating on one band to a different transmitter/receiver on a different band, or from one channel in one band to different channel on that band, the current association had to be broken before a new association could be created. This—"break before make"—was necessary to reduce interference."

EX2017 (Akl Supp. Decl.) at ¶105; Reply 17

Lack of Written Description: "association"

- **Surreply:** Figure 1's APP A and APP D share multiple MAC/PHY pairs, which could represent multiple recipients **Surreply 26**

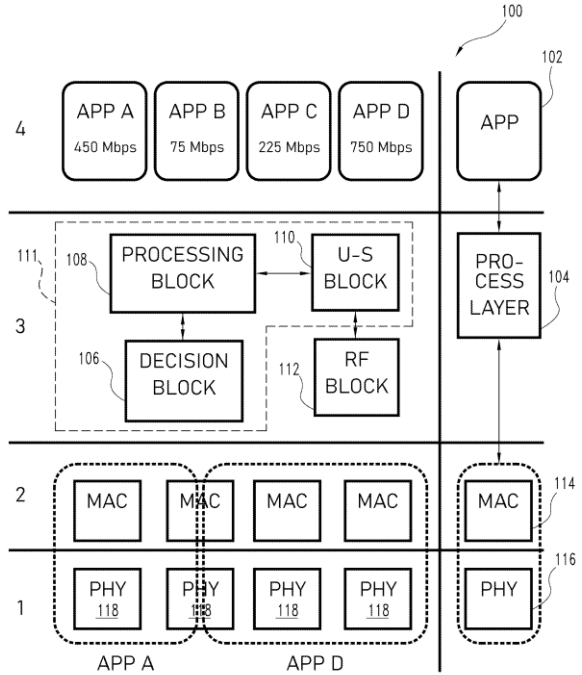


Fig. 1

- **Incorrect:**
  - The claims require a ***single*** recipient associated with ***multiple*** MAC/PHY pairs
  - Nothing in Figure 1 indicates APP A or APP D is transmitting to a ***single*** recipient on ***multiple*** MAC/PHY pairs

Section 112 Lack of Written Description: “without requiring disassociation” (‘546, ‘756, ‘198 patents)

Lack of Written Description: "without requiring disassociation"

Limitation
Transmit "without requiring the disassociation of the recipient from the actual MAC and PHY interfaces"

- The specification does not describe **associations** between a recipient and multiple MAC/PHY interfaces, and so also does not describe **disassociations** or lack thereof

- PO claims simultaneous association was the novelty of the patents, and not within the knowledge of a POSITA:

> "Prior to the XiFi Patents, application data transmitted over a Wi-Fi network was confined to a single band, and any switch to another band required that the association between a transmitter and a receiver on one band be broken before a new association on a different band could be made, i.e., "break before make.""

EX1018 (Complaint) at ¶34; Pet. 93-94

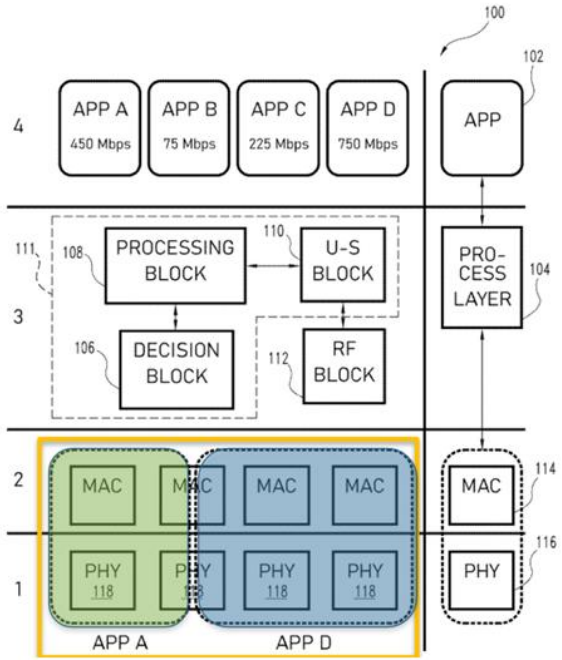
Lack of Written Description: "without requiring disassociation"

"While a negative limitation need not be recited in the specification in haec verba, there generally must be something in the specification that conveys to a skilled artisan that the inventor intended the exclusion, such as a discussion of disadvantages or alternatives… [T]he written description requirement cannot be met through simple disregard of the presence or absence of a limitation."

Novartis Pharms. Corp. v. Accord Healthcare, Inc., 38 F.4th 1013, 1017 (Fed. Cir. 2022)

Lack of Written Description: “without requiring disassociation”

- **PO:** Fig. 1 indicates “make before break” is being employed **POR 84**



- **Incorrect:**
  - A static figure does not disclose “make before break”
  - A static figure does not disclose a single recipient associated with multiple MAC/PHY pairs

Lack of Written Description: “without requiring disassociation”

- **Surreply:** Written description is met because a POSITA understands what “without requiring disassociation” means **Surreply 26-27**

- **Incorrect:**
  - Written description requires sufficient description to show ***possession of the invention***
  - Whether a POSITA understood the plain meaning of the terms is immaterial

Section 112 Lack of Written Description: “utilizing …frequencies [of] the remaining portion” (‘546, ‘756, ‘198 patents)

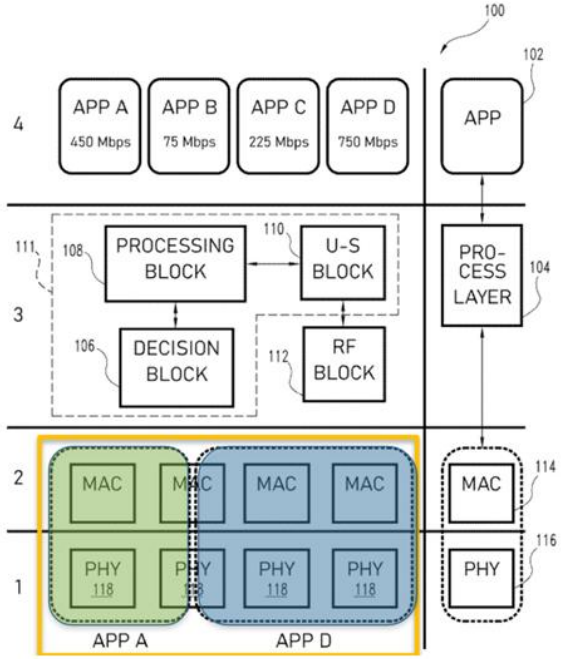
Lack of Written Description: “utilizing …frequencies [of] the remaining portion”

Limitation
Bandwidth utilization “do[es] not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability”

- The specification does not describe **frequency allocation**, much less other devices being able to use the **frequencies** of the remaining bandwidth portions

Lack of Written Description: "utilizing …frequencies [of] the remaining portion"

- **PO:** Fig. 1 provides written description because it indicates sharing of resources by multiple applications, which "could" be multiple recipients **POR 85-86, Surreply 27-28**



- **Incorrect:**
  - Multiple applications does not necessarily imply multiple recipients
  - Nothing in this figure indicates simultaneously using different bandwidth ***frequencies***
    - No depiction or disclosure of ***frequencies*** at all

Section 112 Indefiniteness: “[partially/substantially] simultaneously”
(‘546 claims 15, 18-29, ‘756 claim 27, ‘198 claim 27)

Indefiniteness: "[partially/substantially] simultaneously"



"[C]laims [with terms of degree], when read in light of the specification and the prosecution history, must provide objective boundaries for those of skill in the art."

Interval Licensing LLC v. AOL, Inc., 766 F.3d 1364, 1370 (Fed. Cir. 2014) (citations omitted)

Indefiniteness: "[partially/substantially] simultaneously"

Limitations
A data stream is "partially simultaneously transmitted" to the recipient from both of the transceivers
A data stream is "substantially simultaneously transmitted" to the recipient from both of the transceivers

- Specification provides no guidance on transmissions that are ***partially*** or ***substantially*** simultaneous on multiple transceivers

"Thus, a given radio may handle multiple tasks to receive and broadcast simultaneously, if the bandwidth demands are relatively low, or handle a single task, such as relay radio A**2**, if the bandwidth demand necessitates the need for additional wireless transceiver resources."

Ex. 1001 (564 patent) at 7:49-54

"For example, it is not clear whether transmission or receipt of a data stream within one microsecond, millisecond, second, or minute is within the scope of "partially" simultaneous or "substantially" simultaneous. Because the '564 patent recites both "partially" and "substantially" simultaneously, there must be a difference between the two terms. But the specification the fails to provide any objective guidance to understand what would be "partially" simultaneous compared to "substantially" simultaneous."

564 Ex. 1002 (Almeroth Decl.) at ¶241; 564 Pet. 98

Indefiniteness: "[partially/substantially] simultaneously"

- **PO:** POSITA would have known it means parallel transmissions over a single "transmission opportunity" (TXOP) **564 POR 88**
  - Partially simultaneously: one transmission has less data and finishes sooner
  - Substantially simultaneously: two parallel transmissions of same data essentially overlap

- **Incorrect:**
  - Specification does not mention TXOP at all
  - No objective criteria for "essentially overlap"
  - No objective criteria for where partially ends and substantially begins

18. The wireless networking device of claim **1**, wherein the processing interface is configured to, when the wireless networking device is being used, and in a manner transparent to any layer of the wireless networking device above the processing interface,

munication to at least partially simultaneously transmit the first data stream to the first recipient from both of the first and second wireless transceivers; and

19. The wireless networking device of claim **18**, wherein the first data stream is substantially simultaneously transmitted to the recipient from both of the first and second wireless transceivers.

Indefiniteness: "[partially/substantially] simultaneously"

- **PO:** POSITA would have known it means parallel transmissions over a single "transmission opportunity" (TXOP) **564 POR 88**
  - Partially simultaneously: one transmission has less data and thus finishes sooner
  - Substantially simultaneously: two parallel transmissions of same data essentially overlap

- Tanenbaum:

> "With transmission opportunities, each station gets an equal amount of airtime, not an equal number of frames. Stations that send at a higher rate for their airtime will get higher throughput. In our example, when sending together the 6-Mbps and 54-Mbps senders will now get 3 Mbps and 27 Mbps, respectively."

Ex. 2010 (Tanenbaum) at 261; 564 POR at 309

Indefiniteness: "[partially/substantially] simultaneously"

- **Surreply:** "substantially" is a well understood term, citing pre-*Nautilus* case, *Verve* **564 Surreply at 28-29**

"Expressions such as "substantially" are used in patent documents when warranted by the nature of the invention, in order to accommodate the minor variations that may be appropriate to secure the invention."

"Understanding of this scope may be derived from extrinsic evidence without rendering the claim invalid. … The summary judgment on this ground is vacated; we remand for further proceedings, including any appropriate recourse to extrinsic evidence concerning the usage and understanding of the term "substantially" in relevant context."

Verve, LLC v. Crane Cams, Inc.., 311 F.3d 1116, 1120 (Fed. Cir. 2002)

Section 112 Indefiniteness: “partially satisfy” (‘198 and ‘756 patent)

Indefiniteness: "partially satisfy the bandwidth requirement"

Limitation
Allocate bandwidth "to at least partially satisfy the bandwidth requirement of the data stream."

- Intrinsic evidence provides no objective boundaries between ***partially satisfying*** and ***not satisfying*** bandwidth requirements

"At 204, the process layer 104 determines available resources in the actual MAC and PHY layers 114 and 116, and allocates the available resources to satisfy the bandwidth demands, at 206."

Ex. 1001 (198 patent) at 4:36-39; 198 Pet. at 90

"For example, for an application with a peak bandwidth requirement of 750 Mbps, it is not clear whether aggregating bandwidth portions of two transceivers to allocate 1, 5, or 10 Mbps would qualify as "partially" satisfying the bandwidth requirement of the data stream."

198 Ex. 1002 (Almeroth Decl.) at ¶214

Indefiniteness: “partially satisfy the bandwidth requirement”

- **PO:** “partially” means any amount that contributes to the bandwidth requirement **198 POR at 70**
  - 1, 5, or Mbps all “partially satisfy” a 750 Mbps bandwidth requirement

- **Incorrect:**
  - If any amount of bandwidth meets the limitation, then it reads the claim out of the limitation
  - PO provides no objective boundary between ***partially satisfied*** and ***not satisfied***

Section 112 Indefiniteness: “better than” (‘564 patent)

Indefiniteness: "better than"

Limitations
"if the data transfer characteristics of the *first* identified bandwidth **portion** are **better than** those of the *second* identified bandwidth **portion**" "if the data transfer characteristics of the *second* identified bandwidth **portion** are **better than** those of the *first* identified bandwidth **portion**"

- "better than" is indeterminable and subjective
- Intrinsic evidence does not at all discuss comparing data transfer characteristics, much less determining which is "better"

> "For example, different data links may have varying levels of bandwidth, received signal strength, frame packet error rate, frequency offset, and latency. A POSITA would not be able to evaluate which link is better without knowing which metric to use for that determination. For example, there could be situations where link A may indicate a stronger received signal than link B, but link B indicates a lower frame packet error rate."

564 Ex. 1002 (Almeroth Decl.) at ¶246; 564 Pet. 100

Indefiniteness: "better than"

- **PO:** A POSITA would know how to compare and rank the characteristics disclosed in the specification to determine which achieves transmission more effectively **564 POR at 88-89**
  - Characteristics usually point in the same direction

- **Incorrect:**
  - PO admits that the characteristics don't always "point in the same direction"
  - None of the intrinsic evidence provides objective criteria for weighing the characteristics, or resolving conflicting characteristics

> "But the specification does not identify which such metric controls, how different metrics should be weighed, or how conflicts should be resolved if different metrics point in different directions. In my opinion, the specification does not provide an objective rule for determining which bandwidth portion is "better" in those circumstances.

564 Ex. 1026 (Almeroth Supp. Decl.) at ¶126; 564 Reply 27

Section 112 Indefiniteness: “first wireless transceiver” (‘546 claim 27)

Indefiniteness: claim 27's "first transceiver"

Limitations
Claim 22: "use the **first wireless transceiver** to **transmit**" Claim 26: "The wireless networking device of **claim 22**, … to cause the **second** and **third wireless transceivers** to at least partially simultaneously **receive** a second data stream from the recipient" Claim 27: "The wireless networking device of **claim 26**, wherein the second data stream is substantially simultaneously **received** by both of the **first** and **second wireless** transceivers.

- Claim 27 recites the wrong transceivers receiving data
  - Claim 22 recites that the first transceiver "transmits"
  - Claim 26 recites that the second and third transceiver "receives"
  - Claim 27 recites that the first and second transceiver "receives"

- PO admits this is an "error" and claims they would seek correction with the Court—they did not

Appendix

Appendix: U.S. Pat. No. 12,250,564

(12) **United States Patent**
Manapragada

(10) **Patent No.: US 12,250,564 B2**
(45) **Date of Patent: *Mar. 11, 2025**

(54) **METHOD AND APPARATUS FOR PROCESSING BANDWIDTH INTENSIVE DATA STREAMS USING VIRTUAL MEDIA ACCESS CONTROL AND PHYSICAL LAYERS**

(71) Applicant: **XiFi Networks R&D Inc.**, Cypress, TX (US)

(72) Inventor: **Sai C. Manapragada**, Cypress, TX (US)

(73) Assignee: **XiFi Networks R&D Inc.**, Cypress, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **18/621,425**

(22) Filed: **Mar. 29, 2024**

(65) **Prior Publication Data**

US 2024/0244447 A1 Jul. 18, 2024

Related U.S. Application Data

(63) Continuation of application No. 18/532,175, filed on Dec. 7, 2023, now Pat. No. 11,950,105, which is a (Continued)

(51) **Int. Cl.**
H04W 16/26 (2009.01)
G06K 7/10 (2006.01)

(52) **U.S. Cl.**
CPC ***H04W 16/26*** (2013.01); ***G06K 7/10603*** (2013.01); ***G06K 7/10831*** (2013.01); ***G06K 7/10871*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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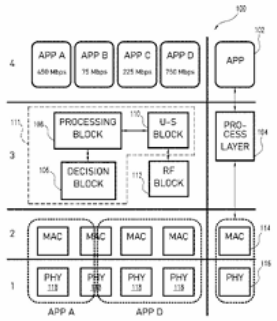
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Primary Examiner — Saad Khawar
(74) *Attorney, Agent, or Firm* — Woodard, Emhardt, Henry, Reeves & Wagner, LLP

(57) **ABSTRACT**

A wireless networking system is disclosed. The wireless networking system includes an application layer associated with one or more applications having a wireless bandwidth requirement. A first wireless transceiver resource associated with an actual MAC layer and PHY layer is employed. The first wireless transceiver resource has a first bandwidth availability up to a first actual bandwidth. A second wireless transceiver resource associated with the actual MAC layer and the PHY layer is employed. The second wireless transceiver resource has a second bandwidth availability up to a second actual bandwidth. A processing layer evaluates the wireless bandwidth requirement and the first and second bandwidth availabilities of the wireless transceiver resources. The processing layer includes a bandwidth allocator to allocate at least a portion of each of the first and second actual bandwidths to virtual MAC and virtual PHY layers, and to satisfy the application layer wireless bandwidth requirement.

29 Claims, 11 Drawing Sheets



Related U.S. Application Data

continuation of application No. 18/448,281, filed on Aug. 11, 2023, now Pat. No. 11,849,337, which is a continuation of application No. 17/468,509, filed on Sep. 7, 2021, now Pat. No. 11,818,591, which is a continuation of application No. 16/039,660, filed on Jul. 19, 2018, now Pat. No. 11,115,834, which is a continuation of application No. 14/526,799, filed on Oct. 29, 2014, now Pat. No. 10,034,179.

(60) Provisional application No. 61/897,216, filed on Oct. 30, 2013, provisional application No. 61/897,219, filed on Oct. 30, 2013.

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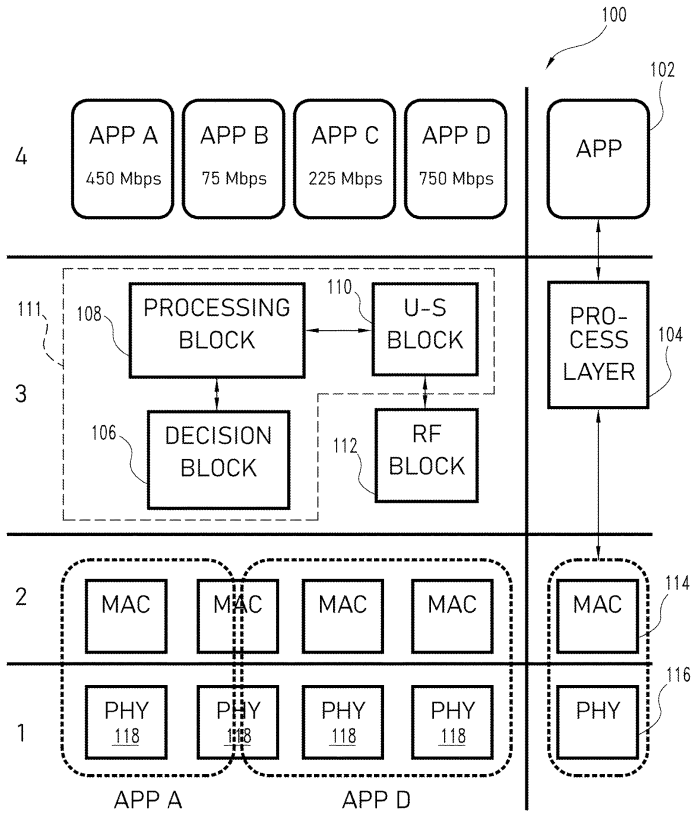


Fig. 1

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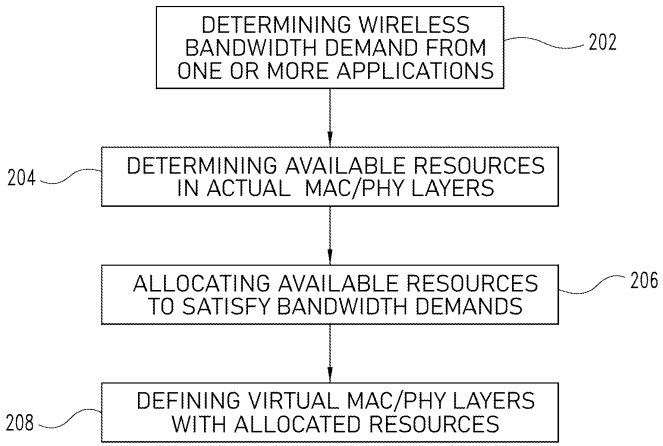


Fig. 2

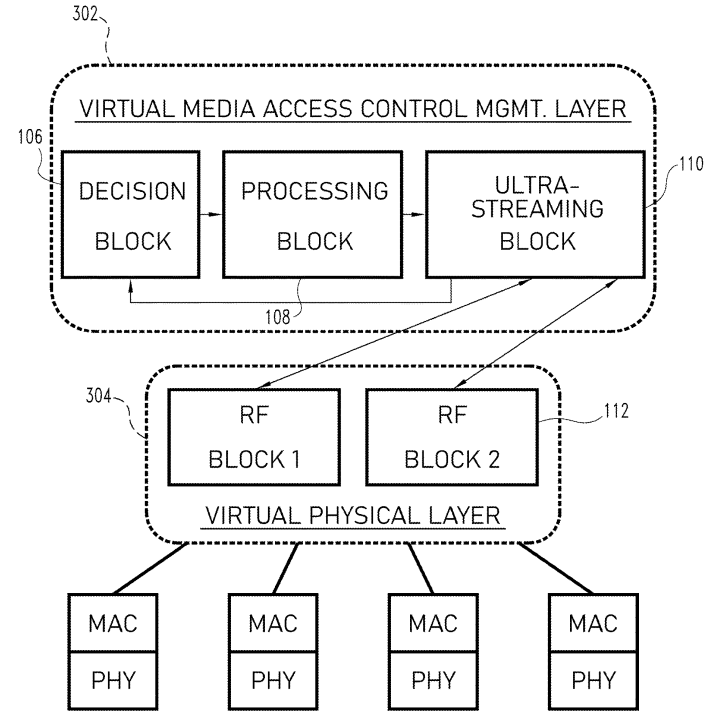


Fig. 3

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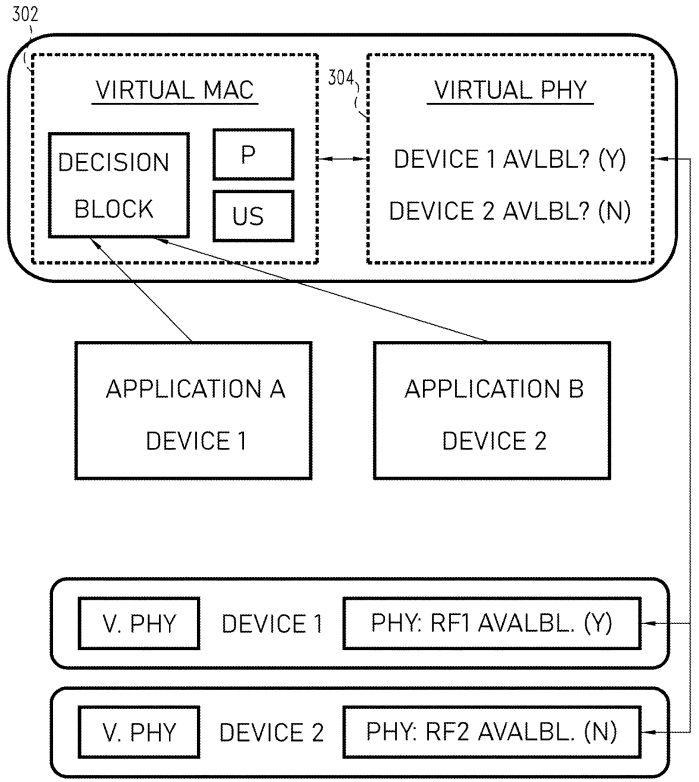


Fig. 4

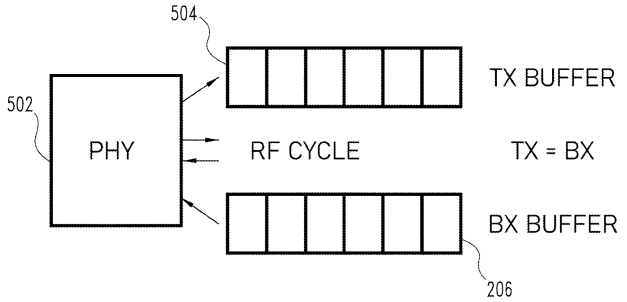


Fig. 5A

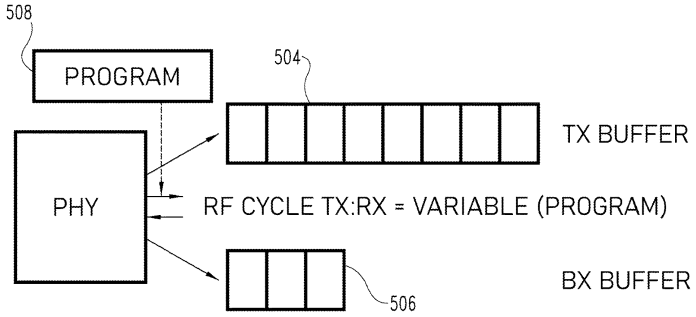


Fig. 5B

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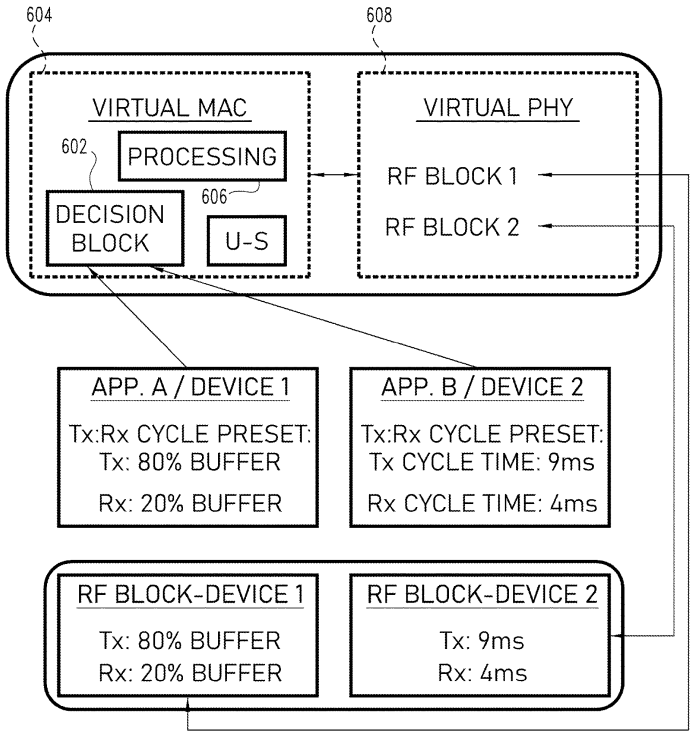


Fig. 6

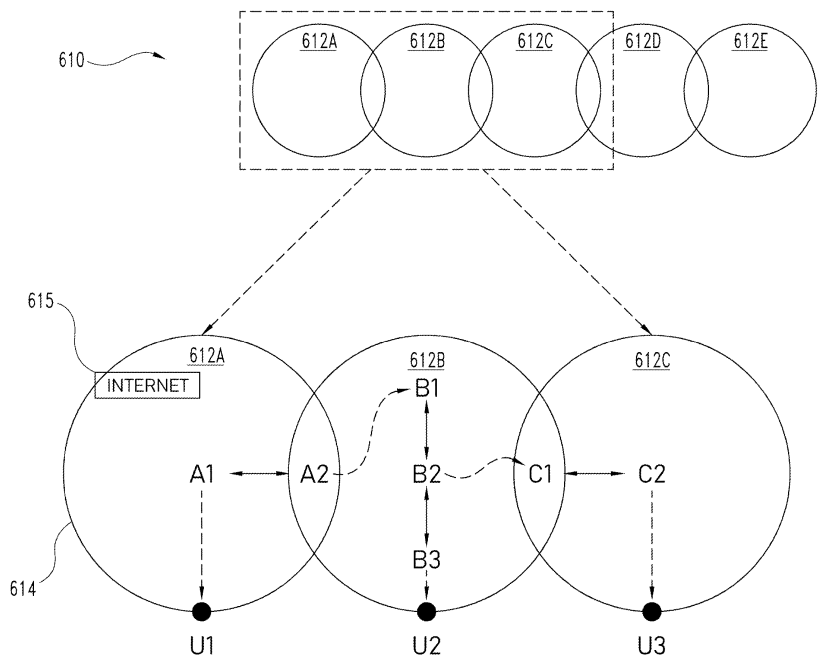


Fig. 7

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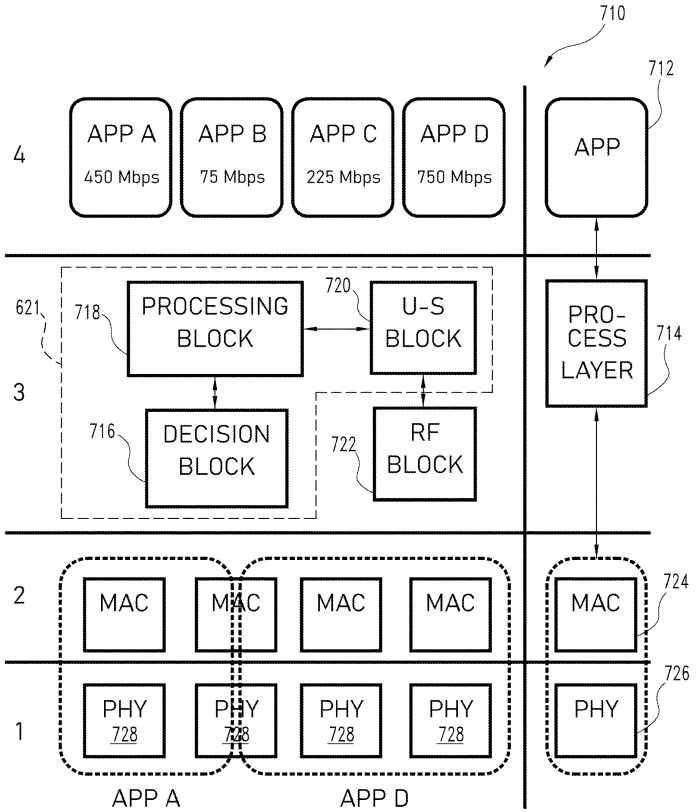


Fig. 8

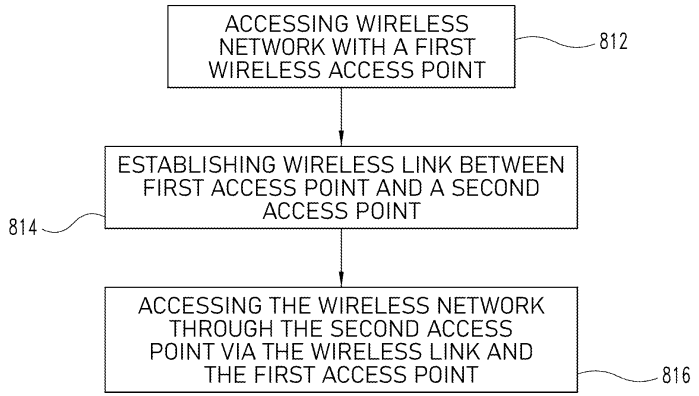


Fig. 9

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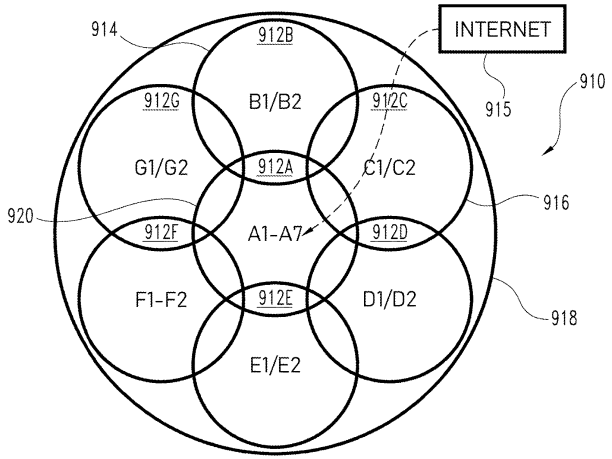


Fig. 10A

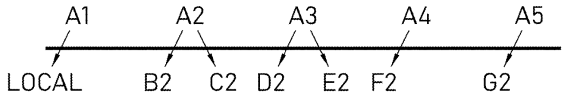


Fig. 10B

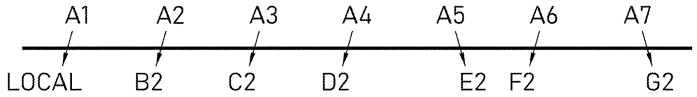


Fig. 10C

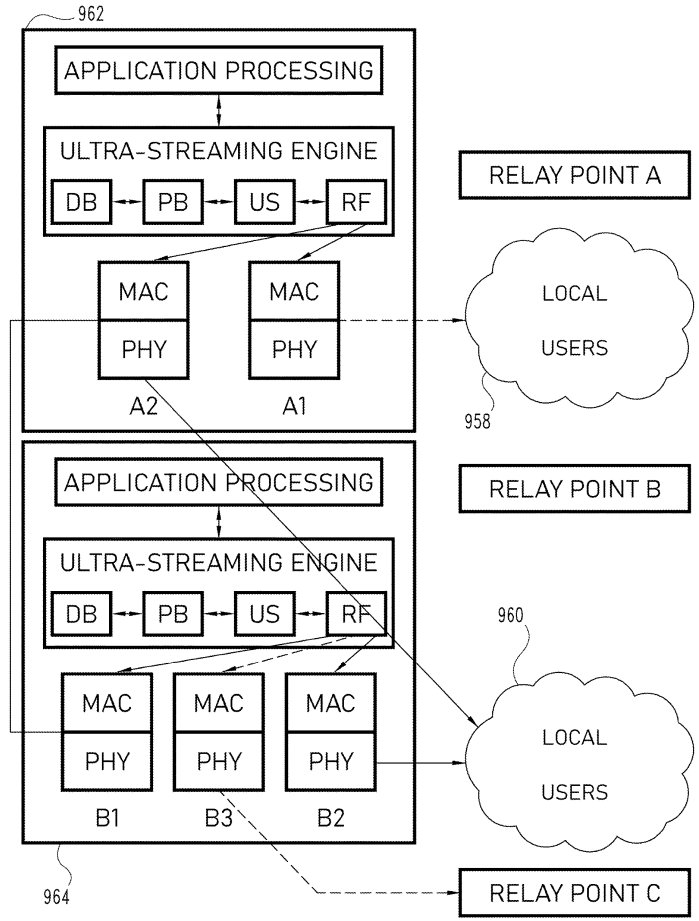


Fig. 11

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METHOD AND APPARATUS FOR PROCESSING BANDWIDTH INTENSIVE DATA STREAMS USING VIRTUAL MEDIA ACCESS CONTROL AND PHYSICAL LAYERS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 18/532,175 filed Dec. 7, 2023, titled "Method and Apparatus for Processing Bandwidth Intensive Data Streams Using Virtual Media Access Control and Physical Layers", which claims the benefit of U.S. patent application Ser. No. 18/448,281 filed Aug. 11, 2023, titled "Method and Apparatus for Processing Bandwidth Intensive Data Streams Using Virtual Media Access Control and Physical Layers", now U.S. Pat. No. 11,849,337, which claims the benefit of U.S. patent application Ser. No. 17/468,509 filed Sep. 7, 2021, titled "Method and Apparatus for Processing Bandwidth Intensive Data Streams Using Virtual Media Access Control and Physical Layers", now U.S. Pat. No. 11,818,591, which claims the benefit of U.S. patent application Ser. No. 16/039,660, filed Jul. 19, 2018, titled "System and Method For Extending Range and Coverage of Bandwidth Intensive Wireless Data Streams", now U.S. Pat. No. 11,115,834, which claims the benefit of U.S. patent application Ser. No. 14/526,799, filed Oct. 29, 2014, titled "System and Method For Extending Range and Coverage of Bandwidth Intensive Wireless Data Streams", now U.S. Pat. No. 10,034,179, which claims the benefit of U.S. Provisional Patent Application Ser. No. 61/897,219, filed Oct. 30, 2013, and U.S. Provisional Patent Application Ser. No. 61/897,216, filed Oct. 30, 2013, all of which are incorporated by reference herein in their entirety.

TECHNICAL FIELD

The disclosure herein relates to wireless networks, and more specifically to high-bandwidth wireless networks for distributing multi-media content.

BACKGROUND

Wireless networks may take many forms, depending on the application. Various WiFi standards exist where users within range of a "hotspot" may establish a wireless link to access a given network. A given hotspot, or wireless access point, typically has a limited range and coverage area. WiFi and cellular technologies rely on very different wireless radios and data protocols in transferring data over the network.

With the proliferation of multi-media content over wireless networks comes an insatiable demand for more bandwidth over the networks. Conventional wireless networking architectures fail to provide adequate resources to efficiently provide optimum range and coverage for wireless network users, and fail to take full advantage of the resources available to satisfy the desire for more bandwidth.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the disclosure are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements and in which:

FIG. **1** illustrates one embodiment of a virtualization mode and an actual mode for processing wireless signals.

FIG. **2** illustrates a flowchart of steps employed in one embodiment of a method of operation of the system of FIG. **1**.

FIG. **3** illustrates how a virtual MAC and virtual PHY are coordinated to manage actual MAC and PHY layers.

FIG. **4** illustrates how the system of FIG. **2** manages signal processing by determining which resources are available.

FIGS. **5**A and **5**B illustrate alternative ways to manage one embodiment of a variable-duplex link.

FIG. **6** illustrates one embodiment of a variable duplex link that is configurable to manage transmit and receive process cycles, including preset process cycle configurations of different types.

FIG. **7** illustrates one embodiment of a system for wirelessly extending range of a wireless network linearly from one access point to another.

FIG. **8** illustrates a wireless management system that utilizes a virtual MAC and virtual PHY to wirelessly and adaptively manage and control multiple radios in a given wireless access point.

FIG. **9** illustrates a flowchart of steps for one embodiment of a method of wirelessly accessing a wireless network, consistent with the systems shown in FIGS. **1** and **2**.

FIG. **10**A-**10**C illustrate embodiments of a system for wirelessly extending range of a wireless network radially from one access point to other access points.

FIG. **11** illustrates one embodiment of multiple wireless management systems that cooperate to allocate transceiver resources between users.

DETAILED DESCRIPTION

Embodiments of wireless networking systems, wireless transceivers and associated methods are disclosed herein. In one embodiment, a wireless networking system is disclosed. The wireless networking system includes an application layer associated with one or more applications having a wireless bandwidth requirement. A first wireless transceiver resource associated with an actual MAC layer and PHY layer is employed. The first wireless transceiver resource has a first bandwidth availability up to a first actual bandwidth. A second wireless transceiver resource associated with the actual MAC layer and the PHY layer is employed. The second wireless transceiver resource has a second bandwidth availability up to a second actual bandwidth. A processing layer evaluates the wireless bandwidth requirement and the first and second bandwidth availabilities of the wireless transceiver resources. The processing layer includes a bandwidth allocator to allocate at least a portion of each of the first and second actual bandwidths to virtual MAC and virtual PHY layers, and to satisfy the application layer wireless bandwidth requirement.

In a further embodiment, a method of a method of operating a wireless transceiver system is disclosed. The wireless transceiver system includes an application layer, actual MAC and PHY layers, and a processing layer between the actual MAC and PHY layers. The method includes evaluating, with processing logic, application bandwidth requirements of applications associated with the applications layer. A virtual MAC layer and a virtual PHY layer are defined between the processing layer and the actual MAC and PHY layers. A bandwidth allocator allocates multiple wireless transceiver resources in the actual MAC and PHY layer to be controlled by the virtual MAC and PHY layer to

satisfy the application bandwidth requirements. A stream of processed data is transferred via a wireless link with the allocated wireless transceiver resources.

In yet another embodiment, a wireless transceiver for coupling to a wireless duplex link is disclosed. The wireless transceiver includes programmable storage, a transmitter and a receiver. The transmitter couples to the programmable storage and transmits data along a wireless link during a first portion of a programmed data transfer cycle. The receiver couples to the programmable storage and receives data from the wireless link during a second portion of the programmed data transfer cycle. The wireless link exhibits an asymmetric transmit/receive profile based on information stored in the programmable storage.

Referring to FIG. **1**, one embodiment of a wireless networking system, generally designated **100**, is shown in an abstract "layer" context. Generally speaking, the system may involve a WiFi network, a mobile wireless network, or a combination of the two. The network includes an application layer "APP", at **102**, with one or more data-intensive software applications "APP A"-"APP D." The individual applications, for example, may have different peak bandwidth requirements in terms of data transfer rates. Thus, for instance, application APP A may have a peak bandwidth requirement of 450 Megabits per second (Mbps), while application APP D may have a peak bandwidth requirement of 750 Mbps.

Further referring to FIG. **1**, the application layer **102** cooperates with a process layer, at **104**. The process layer includes a decision block **106** that interfaces with a processing block **108**. The decision block determines the size and type of data stream being received, and the type of processing necessary to put the stream in a format where it is capable of being transmitted. The processing block processes the data stream as determined by the decision block, and couples to an ultra-streaming block **110**. The ultra-streaming block manages the processing of signal streams or sub-streams given the available resources (memory, processing speed, number of available radios, etc.), and packetizes sufficiently processed streams or sub-streams. The ultra-streaming block feeds data to and from an RF block **112**. While not explicitly shown in FIG. **1**, the ultra-streaming block carries out a monitoring function, more fully described below, that feeds back wireless resource availability to the decision block **106**. Various ways for determining availability of resources include common memory, host interfaces, common threads, and/or queues or other data structures.

The decision block **106**, processing block **108** and ultra-streaming block **110** together form a virtual MAC layer **111**. The RF block **112** forms a virtual PHY layer. As more fully described below, the virtual MAC and PHY layers enable simultaneous allocation of multiple PHY resources for different signal types associated with different applications. As a result, the wireless networking system **100** exhibits significant performance improvements and efficiency advantages.

With continued reference to FIG. **1**, the wireless networking system **100** includes an actual media access control (MAC) layer, at **114**, and an actual physical (PHY) layer, at **116**. The actual MAC layer **114** generally includes software resources capable of controlling one or more transceiver resources **118** that are at the actual PHY layer, such as various radios and receivers. The actual PHY layer **116** may include multiple transceiver resources corresponding to multiple radios, each with an actual data transfer capability, or bandwidth.

The actual PHY layer transceivers may transmit and receive data consistent with a variety of signal protocols, such as High Definition Multimedia Interface (HDMI) consistent with the IEEE 802.11 Standard, Multiple-In Multiple-Out (MIMO), standard Wi-Fi physical control layer (PHY) and Media Access Control (MAC) layer, and existing IP protocols. Additionally, extremely high bandwidth applications such as Voice Over IP (VOIP), streaming audio and video content, multicast applications, convergent and ad-hoc network environment may employ signal protocols consistent with the wireless network system described herein. Additionally, the wireless networking system may be employed and/or embedded into a variety of electronic devices, including wireless access points, base stations, handhelds, tablets, computers, telephones, televisions, DVD players, BluRay players, media players, storage devices, or any such devices that use wireless networks to send and receive data including stand-alone add-on devices such as "dongles" that serve as wireless interfaces between devices.

In operation, and referring to FIG. **2**, the wireless networking system generally determines an overall wireless bandwidth demand or requirement from one or more applications associated with the application layer **102**, at **202**. FIG. **1** illustrates one example, with Application A demanding a peak bandwidth of 450 Mbps, and Application D requiring a peak bandwidth of 750 Mbps. At **204**, the process layer **104** determines available resources in the actual MAC and PHY layers **114** and **116**, and allocates the available resources to satisfy the bandwidth demands, at **206**.

Using the same example shown in FIG. **1**, and assuming that all of the PHY transceivers are available, each PHY transceiver **118** is capable of providing a transmit/receive bandwidth of 300 Mbps. Grouping the entire bandwidth of one transceiver with half the bandwidth of a second satisfies the bandwidth demand for Application A. In a similar manner, allocating the bandwidths of two transceivers, and half the bandwidth of a third transceiver satisfies the bandwidth demand for Application D. The allocating is managed by defining the virtual MAC/PHY layers **111** and **112** with the allocated resources, at **208**.

FIG. **3** illustrates how, in one embodiment, elements associated with the process layer **104** can define a virtual MAC management layer **302** and a virtual PHY layer **304** to enable the sharing of multiple transceiver resources in a way sufficient to satisfy the bandwidth requirements of multiple applications running simultaneously. The virtual MAC and PHY layers manage signals from one or more applications before sending the signals to the actual MAC and PHY layers. The virtual MAC management layer **302** may include the decision block **106**, the processing block **108** and the ultra-streaming block **110**. The virtual PHY layer **304** may include the RF block **112**, shown as multiple RF blocks to denote the virtual use of two sets of allocated transceiver resources. For one embodiment, the RF block(s) communicate directly with the ultra-streaming block about actual resource availability, and the ultra-streaming block sends the information back to the decision block in the virtual MAC layer. Alternatively, the virtual PHY RF block may directly communicate with the virtual MAC decision block and/or the processing block.

Referring now to FIG. **4**, defining the virtual MAC and PHY layers **302** and **304** involves an evaluation of available transceiver resources to meet peak bandwidth demands of applications running in the application layer. One or more applications, such as "Application A" and "Application B", may be initially supported with transceiver resources "Device **1**" and "Device **2**" through an initialization or

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training process at startup. The virtual MAC **302** interfaces with the virtual PHY **304** to determine device availability. This further involves a determination at the PHY layer as to the actual availability of the initially assigned transceiver resources. Should a given resource be unavailable, such as through insufficient bandwidth or having an existing assignment, a replacement resource may be identified and assigned. Availability monitoring may be carried out at initialization, as described above, or through periodic or continuous updating based on environmental conditions or through random on demand programming. Adaptively managing the actual resources provides efficient utilization of resources and power.

For one embodiment, the virtual MAC **302** and virtual PHY **304** may be employed to control respective transmit and receive times (also referred to as an RF cycle) for a transceiver coupled to a variable duplex wireless link. FIG. **5**A illustrates a way of ensuring an RF cycle that has a transmit time equal to a receive time, such that a first amount of data is transmitted along a given link that is equal to a second amount of data that is received along the link. A physical resource PHY **502**, such as a wireless transceiver, is shown coupled to a transmit buffer **504** and a receive buffer **506**. By providing transmit buffer storage that is equal to the receive buffer storage, the amount of data transmitted during both portions of the cycle is equal (since the transceiver generally transmits and receives the entire contents of a given buffer before switching to the next portion of the cycle).

While equal transmit and receive portions of the RF cycle may be beneficial in some circumstances, allocating different PHY resources for different applications, as described above, may benefit from asymmetric wireless links, where the transmit or receive times may be different to optimize wireless data traffic. FIG. **5**B illustrates one embodiment of a variable duplex link that includes a transmit buffer **504** that is larger than a receive buffer **506**. A programmable register **508** provides a way to specify the storage capacities of each of the buffers, thus enabling control of the respective transmit and receive time. In another embodiment, the programmable register may include storage to specify precise transmit and receive times for the RF cycle in addition to, or instead of varying the buffer sizes. For some embodiments, sub-programmable mask intervals may be programmed which disable a given transmitter or receiver during the pre-programmed transmit or receive time.

FIG. **6** illustrates one embodiment of the wireless networking system, described above, utilizing the variable duplex link to optimize uplink (transmit) and downlink (receive) data transfer efficiency for a given application. As shown in FIG. **6**, a decision block **602** associated with a virtual MAC **604** detects application types, APP A and APP B, for which a preset transmit/receive cycle ratio has been assigned. A processing block **606** processes the substream signals together with the preset cycle ratio information. A virtual PHY **608**, configures available devices to the preset cycle ratio in terms of either configuring transmit and receive buffer sizes, and/or configuring actual transmit and receive cycle times.

The virtual MAC and PHY layers **604** and **608** may also be used to reconfigure, or update, the RF cycle times of the link periodically or continuously. Additionally, random on-demand programming may be employed to reconfigure the link. By monitoring parameters associated with the link, a predictive model of optimal link operation may be adaptively generated, resulting in enhanced link operability.

Those skilled in the art will appreciate that the embodiments described above enable wireless networking systems to operate at higher levels of performance and with better efficiencies. By employing a virtual MAC and virtual PHY between an application layer and an actual MAC and PHY layer, wireless transceiver resources may be allocated more efficiently to handle various data bandwidth requirements from different applications. Additionally, by selectively employing a variable duplex link, data transfers may be further optimized through finer control of link transmit and receive times.

When received within a computer system via one or more computer-readable media, such data and/or instruction-based expressions of the above described circuits may be processed by a processing entity (e.g., one or more processors) within the computer system in conjunction with execution of one or more other computer programs including, without limitation, net-list generation programs, place and route programs and the like, to generate a representation or image of a physical manifestation of such circuits. Such representation or image may thereafter be used in device fabrication, for example, by enabling generation of one or more masks that are used to form various components of the circuits in a device fabrication process.

Further embodiments of wireless networking systems, wireless transceivers and associated methods are disclosed herein. In one embodiment, a wireless networking system is disclosed. The system includes a first wireless access point having a first coverage area. The first wireless access point includes a first wireless transceiver to access a wireless network and a second wireless transceiver coupled to the first wireless transceiver. A second wireless access point has a second coverage area. The second wireless access point includes a third wireless transceiver for establishing a wireless link with the second wireless transceiver, and a fourth wireless transceiver coupled to the third wireless transceiver to provide user access to the wireless link. User access to the wireless link accesses the wireless network via the second and first wireless transceivers.

In a further embodiment, a method of providing wireless network access to a user is disclosed. The method includes accessing a wireless network with a first wireless transceiver associated with a first wireless access point. The first wireless access point has a first coverage area bounded by a range of a first broadcast transceiver associated with the first wireless access point. Wireless access to the wireless network is enabled within the first coverage area with the first broadcast transceiver. A wireless link is established between the first wireless access point and a third wireless transceiver associated with a second wireless access point. The second wireless access point has a second coverage area bounded by a fourth wireless transceiver. The fourth wireless transceiver is in communication with the third wireless transceiver. Access to the wireless network from within the second coverage area is enabled via the fourth wireless transceiver.

In yet another embodiment, a wireless access point for use in a wireless networking system, the wireless access point includes a first wireless transceiver to establish a wireless link to a wireless network. A second wireless transceiver provides wireless access to the wireless link within a first coverage area. A third wireless transceiver establishes a wireless link to a second wireless access point. Processing logic controls each of the first, second and third wireless transceivers.

Referring to FIG. **7**, one embodiment of a wireless networking system is shown, generally designated **610**, that increases the range of wireless network access. The wireless

networking system **610** includes multiple wireless access points, or nodes, **612**A-**612**E. The nodes may be positioned linearly, such as in serial or wirelessly daisy-chained arrangement, to linearly extend wireless network access across multiple access point coverage zones. A similar embodiment that extends coverage radially is described below with reference to FIGS. **10**A-**10**C.

With continued reference to FIG. **7**, for one specific embodiment, node **612**A includes multiple radios A**1** and A**2**. Radio A**1** is configured as a receiver/transmitter (transceiver) that exhibits a wireless transceiver range, denoted by the circle at **614**, to receive and transmit signals to a network, such as the Internet **615**. Note that for purposes of clarity, each node is shown in FIG. **7** as having a range defined by the range of one of the radios. Radio A**1**, while acting as a receiver/transmitter (often referred to herein as a transceiver) is also able to broadcast and receive signals within its coverage area to users that are in the area **614**, thereby serving as a wireless access point for that area. User U**1** thus may access the Internet via radio A**1**. Radio A**1** also communicates with a relay radio A**2**, which may be disposed near the periphery of the range **104** of radio A**1**. Relay radio A**2** has a similar range as radio A**1**, and is able to communicate with radio B**1** that is associated with node **612**B. For some embodiments, the relay radio (such as radio A**2**) for a given node is assigned to one or more dedicated transceivers (such as B**1**) associated with respective adjacent nodes. Additionally, in general, the transceivers of a given node can communicate to any of the transceivers available in adjacent nodes.

Further referring to FIG. **7**, node **612**B includes three radios, one to establish communication with radio A**2** of node **612**A, a second radio B**2** to act as a relay to a third node **612**C, and a third radio B**3** to act as a wireless access point to a second user U**2** within the node **102**B. The third node **102**C includes a first radio C**1** to communicate with the second radio B**2** of the second node **612**B, and a second radio C**2** to provide wireless access to a third user U**3** within the access coverage area of the third node **612**C. Thus, with communication links established from the Internet to radio A**1**, to radio A**2**, to radio B**1** to radio B**2** to radio C**1** and to radio C**2**, the user U**3** is able to access the Internet wirelessly even though the distance between the user U**3** to the first wireless access point A**1** exceeds the coverage or range of radio A**1**.

Each node **612**A-**612**C described above, may be configured differently depending on the available resources and bandwidth demands. Thus, a given radio may handle multiple tasks to receive and broadcast simultaneously, if the bandwidth demands are relatively low, or handle a single task, such as relay radio A**2**, if the bandwidth demand necessitates the need for additional wireless transceiver resources.

To manage the allocation and configuration of wireless transceiver resources, each node employs a management system, such as one embodiment shown in FIG. **8**, and generally designated **710**. The management systems for multiple nodes thus forms distributed logic that cooperate to efficiently manage bandwidth utilization for users. Further details of the management system for a variety of applications are disclosed in U.S. Pat. No. 9,788,305, titled METHOD AND APPARATUS FOR PROCESSING BANDWIDTH INTENSIVE DATA STREAMS USING VIRTUAL MEDIA ACCESS CONTROL AND PHYSICAL LAYERS, filed Oct. 29, 2014, and expressly incorporated herein by reference.

Further referring to FIG. **8**, one specific embodiment of the management system **710**, is shown in a networking "layer" context. Generally speaking, the wireless management system may be configured for coupling an available transceiver resource to a WiFi network, a mobile wireless network, or a combination of the two. The management system **710** includes an application layer "APP", at **712**, with one or more data-intensive software applications "APP A"-"APP D." The individual applications, for example, may have different peak bandwidth requirements in terms of data transfer rates. Thus, for instance, application APP A may have a peak bandwidth requirement of 450 Megabits per second (Mbps), while application APP D may have a peak bandwidth requirement of 750 Mbps.

Further referring to FIG. **8**, the application layer **712** cooperates with a process layer, at **714**. The process layer includes a decision block **716** that interfaces with a processing block **718**. The decision block determines the size and type of data stream being received, and the type of processing necessary to put the stream in a format where it is capable of being transmitted. The processing block processes the data stream as determined by the decision block, and couples to an ultra-streaming block **720**. The ultra-streaming block manages the processing of signal streams or sub-streams given the available resources (memory, processing speed, number of available radios, etc.), and packetizes sufficiently processed streams or sub-streams. The ultra-streaming block feeds data to and from an RF block **722**. While not explicitly shown in FIG. **8**, the ultra-streaming block carries out a monitoring function, more fully described below, that feeds back wireless resource availability to the decision block **716**. Various ways for determining availability of resources include common memory, host interfaces, common threads, and/or queues or other data structures.

The decision block **716**, processing block **718** and ultra-streaming block **720** together form a virtual MAC layer **621**. The RF block **722** forms a virtual PHY layer. The virtual MAC and PHY layers enable simultaneous allocation of multiple PHY resources for different signal types associated with different applications. Transceiver configurations may be applied at initialization of the system, periodically during normal operation, or randomly on demand during operation. As a result, the most efficient path for wireless access between a given user and the wireless network is paved. The wireless networking system **710** thus exhibits significant performance improvements and efficiency advantages.

With continued reference to FIG. **8**, the wireless management system **710** includes an actual media access control (MAC) layer, at **724**, and an actual physical (PHY) layer, at **726**. The actual MAC layer **724** generally includes software resources capable of controlling one or more transceiver resources **728** that are at the actual PHY layer, such as various radios and receivers. The actual PHY layer **726** may include multiple transceiver resources corresponding to multiple radios, each with an actual data transfer capability, or bandwidth.

The actual PHY layer transceivers may transmit and receive data consistent with a variety of signal protocols, such as High Definition Multimedia Interface (HDMI) consistent with the IEEE 802.11 Standard, Multiple-In Multiple-Out (MIMO), standard Wi-Fi physical control layer (PHY) and Media Access Control (MAC) layer, and existing IP protocols. Additionally, extremely high bandwidth applications such as Voice Over IP (VOIP), streaming audio and video content, multicast applications, convergent and ad-hoc network environment may employ signal protocols consis-

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tent with the wireless network system described herein. Additionally, the wireless management system may be employed and/or embedded into a variety of electronic devices, including wireless access points, base stations, handhelds, tablets, computers, telephones, televisions, DVD players, BluRay players, media players, storage devices, or any such devices that use wireless networks to send and receive data including stand-alone add-on devices such as "dongles" that serve as wireless interfaces between devices.

FIG. **9** illustrates a flowchart that shows generic steps carried out during operation of the wireless networking system of FIG. **7**. At **812**, the first node **612**A (FIG. **7**) accesses a wireless network, such as the Internet **615**, with a first radio or transceiver A**1**. A second transceiver A**2**, establishes a wireless link with the first transceiver A**1**, at **814**. The second transceiver may then act as a relay to establish a further link with a radio in a different node, such as radio B**1** in node **612**B. The wireless network may then be accessed through the different node **612**B via the wireless link (between radios B**1** and A**2**) and the first access point, at **816**. By employing a plurality of transceivers at each of the nodes that run the Ultra Streaming engine to allocate their available resources, either at initialization as configurable, or while in operation periodically, or dynamically in random demand while in operation, the most efficient path for wireless access is accomplished. This results in increased range and coverage for a given wireless network, and it's Internet access.

FIGS. **10**A-**10**C illustrate a further embodiment of a wireless networking system, generally designated **910**, that is similar to the system of FIG. **7**, but configured with various nodes **912**A-**912**G that are positioned in a relative manner to extend coverage radially, rather than linearly. Each of the nodes includes a wireless management system, such as that shown in FIG. **8** and described above.

Further referring to FIG. **10**A, a first node **912**A includes radios A**1**-A**7**, with radio A**1** acting as an originating access point for a local network signal, such as the Internet **915**. The remaining radios A**2**-A**7** may then be configured to communicate with specified adjacent nodes. The adjacent nodes have respective coverage zones that overlap the primary node **912**A radially outwardly. Thus, by encircling the primary node with the other nodes, the corresponding coverage area may be increased dramatically.

FIG. **10**B illustrates one configuration where radio A**1** acts as the originating radio to communicate with the local wireless network, and radio A**2** communicates the network signal as a relay with radios B**2** and C**2** of nodes **912**B and **912**C. Radios B**1** and C**1** of each respective node broadcast wireless access to users within the respective coverage zones, bounded by coverage rings **914** and **916** associated with each respective node **912**B and **912**C. Similar arrangements are managed with radio A**3** communicating with radios D**2** and E**2**, and radios A**4** and A**5** communicating with F**2** and G**2**, respectively. To optimize coverage radially, the nodes **912**B-**912**G are positioned radially around the primary node **912**A in a honeycomb structure. The resulting coverage boundary, represented by the coverage circle **408**, is significantly larger than the originating access coverage area (represented by ring **410**) provided by the broadcast radio associated with node **402**A by itself.

FIG. **10**C illustrates different assignments of the radios in the wireless networking system of FIG. **10**A managed by the wireless management system **910** of each node **912**A-**912**G. The assignments and radio configurations may be defined and managed during an initialization process, periodically during operation, or randomly on demand depending on the bandwidth demands of the system. Thus, if bandwidth demands are higher in nodes **912**B and **912**C, then instead of sharing the bandwidth of radio A**2** with nodes **912**B (radio B**2**) and **912**C (radio C**2**), such as the arrangement of FIG. **10**B, dedicated relay radios A**2** and A**3** may be assigned to each of those nodes so that maximum bandwidth may be provided to each, resulting in radio A**2** communicating with radio B**2** and radio A**3** communicating with radio C**2** (FIG. **10**C).

For some embodiments, whether the wireless networking system is configured as a linear or radial architecture, there may be multiple transceivers assigned to a wireless node, and each node may have multiple transceivers assigned to a given user. FIG. **11** illustrates how multiple wireless management systems cooperate to efficiently allocate transceiver resources in such a situation. A first node management system **962** may control transceiver resources A**1** and A**2** within a first node. A second management system **964** may control transceiver resources B**1**, B**2**, and B**3**. The management systems **962** and **964** communicate with each other to determine the optimal resource allocation to service respective local users, at **958** and **960**.

Thus, for the example shown in FIG. **11**, the first local user **958** within the coverage of the first node may need bandwidth that may be sufficiently provided by transceiver A**1** alone. The second local user **960**, positioned within the vicinity of both the first and second nodes, may be assigned transceiver A**2** from the first node, and transceiver B**2** from the second node, thereby having access to twice the bandwidth. Other examples may involve partial transceiver allocations, where a portion of the transceiver bandwidth is allocated to a first user, and a second portion of the bandwidth allocated to a second user.

In some embodiments, a given wireless link may be configured as a variable duplex link. Each wireless management system may task the virtual MAC and virtual PHY to control respective transmit and receive cycles for one or more of the wireless transceivers. Varying the transmit and/or receive times may be accomplished in various ways, such as through programmable buffer resources and/or through programmable transmit and receive times. Further detail of such a variable duplex wireless link may be found in U.S. Pat. No. 9,788,305, titled METHOD AND APPARATUS FOR PROCESSING BANDWIDTH INTENSIVE DATA STREAMS USING VIRTUAL MEDIA ACCESS CONTROL AND PHYSICAL LAYERS, filed Oct. 29, 2014, and expressly incorporated herein by reference.

Those skilled in the art will appreciate that the embodiments described above enable efficient wireless access to wireless networking systems by users that might be outside the range of a single wireless access point. By employing linear and/or radial wireless access system architectures, and configuring available wireless transceiver resources optimally within each node, a given wireless network may be accessed with greater bandwidth and more efficiently.

When received within a computer system via one or more computer-readable media, such data and/or instruction-based expressions of the above described circuits may be processed by a processing entity (e.g., one or more processors) within the computer system in conjunction with execution of one or more other computer programs including, without limitation, net-list generation programs, place and route programs and the like, to generate a representation or image of a physical manifestation of such circuits. Such representation or image may thereafter be used in device fabrication, for example, by enabling generation of one or more masks that are used to form various components of the circuits in a device fabrication process.

In the foregoing description and in the accompanying drawings, specific terminology and drawing symbols have been set forth to provide a thorough understanding of the present invention. In some instances, the terminology and symbols may imply specific details that are not required to practice the invention. For example, any of the specific numbers of bits, signal path widths, signaling or operating frequencies, component circuits or devices and the like may be different from those described above in alternative embodiments. Also, the interconnection between circuit elements or circuit blocks shown or described as multi-conductor signal links may alternatively be single-conductor signal links, and single conductor signal links may alternatively be multi-conductor signal links. Signals and signaling paths shown or described as being single-ended may also be differential, and vice-versa. Similarly, signals described or depicted as having active-high or active-low logic levels may have opposite logic levels in alternative embodiments. Component circuitry within integrated circuit devices may be implemented using metal oxide semiconductor (MOS) technology, bipolar technology or any other technology in which logical and analog circuits may be implemented. With respect to terminology, a signal is said to be "asserted" when the signal is driven to a low or high logic state (or charged to a high logic state or discharged to a low logic state) to indicate a particular condition. Conversely, a signal is said to be "deasserted" to indicate that the signal is driven (or charged or discharged) to a state other than the asserted state (including a high or low logic state, or the floating state that may occur when the signal driving circuit is transitioned to a high impedance condition, such as an open drain or open collector condition). A signal driving circuit is said to "output" a signal to a signal receiving circuit when the signal driving circuit asserts (or deasserts, if explicitly stated or indicated by context) the signal on a signal line coupled between the signal driving and signal receiving circuits. A signal line is said to be "activated" when a signal is asserted on the signal line, and "deactivated" when the signal is deasserted. Additionally, the prefix symbol "/" attached to signal names indicates that the signal is an active low signal (i.e., the asserted state is a logic low state). A line over a signal name (e.g., '<signalname>') is also used to indicate an active low signal. The term "coupled" is used herein to express a direct connection as well as a connection through one or more intervening circuits or structures. Integrated circuit device "programming" may include, for example and without limitation, loading a control value into a register or other storage circuit within the device in response to a host instruction and thus controlling an operational aspect of the device, establishing a device configuration or controlling an operational aspect of the device through a one-time programming operation (e.g., blowing fuses within a configuration circuit during device production), and/or connecting one or more selected pins or other contact structures of the device to reference voltage lines (also referred to as strapping) to establish a particular device configuration or operation aspect of the device. The term "exemplary" is used to express an example, not a preference or requirement.

While the invention has been described with reference to specific embodiments thereof, it will be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention. For example, features or aspects of any of the embodiments may be applied, at least where practicable, in combination with any other of the embodiments or in place of counterpart features or aspects thereof. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A wireless networking device, comprising:

a processing interface that is connected to an application interface, the application interface being associated with a first application, the first application providing, when the wireless networking device is being used, a first data stream and having a first wireless bandwidth requirement;

first and second actual MAC interfaces connected to the processing interface;

first and second actual PHY interfaces respectively connected to the first and second actual MAC interfaces;

first and second wireless transceivers respectively associated with the first and second actual PHY interfaces, wherein each of the first and second wireless transceivers is suitable for use in a wireless local area network, and the first and second wireless transceivers, respectively, (i) have a first and second bandwidth availability up to first and second actual bandwidths, and (ii) are adapted to emit radio waves in first and second different bands of frequencies;

at least one virtual MAC interface and at least one resource monitoring interface formed in the processing interface that, during operation of the wireless networking device, feeds information regarding the bandwidth availabilities of the first and second wireless transceivers back to the at least one virtual MAC interface;

wherein the processing interface is configured to, when the wireless networking device is being used, and in a manner transparent to any layer of the wireless networking device above the processing interface,

(a) request or create (i) a first association between a recipient and the first actual MAC and PHY interfaces and (ii) a second association between the recipient and the second actual MAC and PHY interfaces,

(b) identify at least one first and second portions of the first actual bandwidth of the first wireless transceiver, each one of the first and second identified bandwidth portions each having a set of given resources,

(c) evaluate the data transfer characteristics of the given resources of both the first and second identified bandwidth portions,

(d) if the data transfer characteristics of the first identified bandwidth portion are better than those of the second identified bandwidth portion, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the first identified bandwidth portion that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

(e) if the data transfer characteristics of the second identified bandwidth portion are better than those of the first identified bandwidth portion, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the

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given resources of the second identified bandwidth portion that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

wherein, when the wireless networking is being used, the wireless networking device's utilization of the first and second identified bandwidth portions do not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the first wireless transceiver for data transmission or reception purposes at the same time that the first or second identified bandwidth portions are being used for data transmission purposes.

2. The wireless networking device of claim **1**, wherein the wireless networking device comprises a wireless access point.

3. The wireless networking device of claim **1**, wherein the first and second frequency bands are specified in at least one member of the family of IEEE 802.11 standards that was in existence as of Oct. 30, 2013.

4. The wireless networking device of claim **1**, wherein the at least one virtual MAC interface includes a decision block.

5. The wireless networking device of claim **1**, wherein the at least one virtual MAC interface includes a processing block.

6. The wireless networking device of claim **1**, wherein the at least one virtual MAC interface includes an ultra-streaming block.

7. The wireless networking device of claim **1**, wherein the resource monitoring interface includes an RF block.

8. The wireless networking device of claim **1**, wherein the processing interface comprises multiple resource monitoring interfaces.

9. The wireless networking device of claim **1**, wherein the processing interface comprises multiple virtual MAC interfaces.

10. The wireless networking device of claim **1**, wherein the processing interface includes a bandwidth allocator.

11. The wireless networking device of claim **1**, wherein the first identified actual bandwidth portion is contiguous.

12. The wireless networking device of claim **1**, wherein the second identified actual bandwidth portion is contiguous.

13. The wireless networking device of claim **1**, wherein the resource monitoring interface is not contiguous with the at least one virtual MAC interface.

14. The wireless networking device of claim **1**, wherein the data transfer characteristics of at least one of the first and second identified bandwidth portions of the first wireless transceiver are representative of one or more environmental conditions where the wireless networking device is used.

15. The wireless networking device of claim **1**, wherein the processing interface is configured to, when the wireless networking device is being used, in a manner transparent to any layer of the wireless networking device above the processing interface, aggregate the first and second identified actual bandwidth portions to at least partially simultaneously transmit the first data stream to the first recipient from the first wireless transceiver.

16. The wireless networking device of claim **1**, wherein the processing interface is configured to, when the wireless networking device is being used, and in a manner transparent to any layer of the wireless networking device above the processing interface,

(a) identify at least one first portion of the second actual bandwidth of the second wireless transceiver, the first identified bandwidth portion of the second wireless transceiver comprising a set of given resources,

(b) evaluate data transfer characteristics of the given resources of the first identified bandwidth portion of the second wireless transceiver,

(c) if the data transfer characteristics of the first identified bandwidth portion of the first wireless transceiver are better than the data transfer characteristics of the first identified bandwidth portion of the second wireless transceiver, use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the first identified bandwidth portion of the first wireless transceiver that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

(d) if the data transfer characteristics of the first identified portion of the second wireless transceiver are better than the data transfer characteristics of the first identified bandwidth portion of the first wireless transceiver, use the second wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of the recipient from either or both of the first and second actual MAC and PHY interfaces, using a subset of frequencies corresponding to only the given resources of the first identified bandwidth portion of the second wireless transceiver that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application; and

wherein, when the wireless networking is being used, the wireless networking device's utilization of the first identified available bandwidth portion of the second wireless transceiver does not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the second wireless transceiver for data transmission or reception purposes at the same time that the first identified bandwidth portion is being used.

17. The wireless networking device of claim **16**, wherein the data transfer characteristics of at least one of the first identified bandwidth portion of the first wireless transceiver and the first identified bandwidth portion of the second wireless transceiver are representative of one or more environmental conditions where the wireless networking device is used.

18. The wireless networking device of claim **1**, wherein the processing interface is configured to, when the wireless networking device is being used, and in a manner transparent to any layer of the wireless networking device above the processing interface,

(a) identify at least one first portion of the second actual bandwidth of the second wireless transceiver, wherein the first identified bandwidth portion of the second wireless transceiver comprises a set of given resources, and

(b) aggregate the given resources of the first identified bandwidth portion of the first wireless transceiver that are available for communication with the given resources of the first identified bandwidth portion of the second wireless transceiver that are available for communication to at least partially simultaneously transmit the first data stream to the first recipient from both of the first and second wireless transceivers; and

wherein, when the wireless networking device is being used, the wireless networking device's utilization of the first identified available bandwidth portion of the second wireless transceiver does not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the second wireless transceiver for data transmission or reception purposes at the same time that the first identified bandwidth portion is being used.

19. The wireless networking device of claim **18**, wherein the first data stream is substantially simultaneously transmitted to the recipient from both of the first and second wireless transceivers.

20. The wireless networking device of claim **15**, wherein the processing interface is configured to, when the wireless networking device is being used, and in a manner transparent to any layer of the wireless networking device above the processing interface,

(a) identify at least one first portion of the second actual bandwidth of the second wireless transceiver, wherein the first identified bandwidth portion of the second wireless transceiver comprises a set of given resources, and

(b) aggregate the given resources of the first identified bandwidth portion of the first wireless transceiver that are available for communication with the given resources of the first identified bandwidth portion of the second wireless transceiver that are available for communication to cause the first and second wireless transceivers to at least partially simultaneously receive a second data stream from the recipient; and

wherein, when the wireless networking is being used, the wireless networking device's utilization of the first identified available bandwidth portion of the second wireless transceiver does not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the second wireless transceiver for data transmission or reception purposes at the same time that the first identified bandwidth portion is being used.

21. The wireless networking device of claim **20**, wherein the second data stream is substantially simultaneously received by both of the first and second wireless transceivers.

22. The wireless networking device of claim **1**, wherein the processing interface is configured to, when the wireless networking device is being used, in a manner transparent to any layer of the wireless networking device above the processing interface,

(a) identify at least one first portion of the second actual bandwidth of the second wireless transceiver, wherein the first identified bandwidth portion of the second wireless transceiver comprises a set of given resources,

(b) use the first wireless transceiver to transmit the first data stream to the recipient, without requiring disassociation of either or both of the first and second associations, using a specific subset of frequencies corresponding to the given resources of the first identified bandwidth portion of the first wireless transceiver that are available for communication to thereby at least partially satisfy the first wireless bandwidth requirement of the first application, and

(c) use the second wireless transceiver to receive a second data stream from the recipient at least partially simultaneously with the first data stream being transmitted to the recipient from the first wireless transceiver, without requiring disassociation of either or both of the first and second associations, using a specific subset of frequencies corresponding to only the given resources of the first identified bandwidth portion of the second wireless transceiver that are available for communication to thereby at least partially satisfy a second wireless bandwidth requirement associated with the second data stream; and

wherein, when the wireless networking is being used, the wireless networking device's utilization of the first identified available bandwidth portion of the second wireless transceiver does not prevent any wireless networking device from utilizing a range of frequencies corresponding to the remaining portion of the bandwidth availability of the second wireless transceiver for data transmission or reception purposes at the same time that the first identified bandwidth portion is being used.

23. The wireless networking device of claim **22**, wherein the second data stream is received by the second wireless transceiver substantially simultaneously with the transmission of the first data stream from the first wireless transceiver.

24. The wireless networking device of claim **22**, wherein the start of the reception of the second data stream by the second wireless transceiver is substantially simultaneous with the start of the transmission of the first data stream from the first wireless transceiver.

25. The wireless networking device of claim **22**, wherein the end of the reception of the second data stream by the second wireless transceiver is substantially simultaneous with the end of the transmission of the first data stream from the first wireless transceiver.

26. The wireless networking device of claim **22**, wherein the processing interface is configured to, when the wireless networking device is being used, in a manner transparent to any layer of the wireless networking device above the processing interface, aggregate at least one first portion of an actual bandwidth of a third wireless transceiver with the given resources of the first identified bandwidth portion of the second wireless transceiver that are available for communication to cause the second and third wireless transceivers to at least partially simultaneously receive a second data stream from the recipient.

27. The wireless networking device of claim **26**, wherein the second data stream is substantially simultaneously received by both of the first and second wireless transceivers.

28. The wireless networking device of claim **22**, wherein the processing interface is configured to, when the wireless networking device is being used, in a manner transparent to any layer of the wireless networking device above the processing interface, aggregate the given resources of the first and second identified actual bandwidth portions of the first wireless transceiver that are available for communication to at least partially simultaneously transmit the first data stream to the first recipient from the first wireless transceiver.

29. The wireless networking device of claim **28**, wherein the first data stream is substantially simultaneously transmitted by the first wireless transceiver.

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[Continued on next page]

(54) Title: OPPORTUNISTIC RADIO ACCESS TECHNOLOGY SELECTION AND AGGREGATION

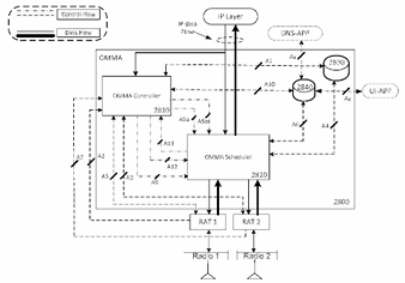


FIG. 28

(57) Abstract: Systems, methods, and instrumentalities are provided for managing multiple radio access technology (RAT) interfaces to enable opportunistic RAT selection and aggregation for sending data traffic over the multiple RAT interfaces. A system for selecting a RAT may include an Internet Protocol (IP) layer and RAT protocol stacks residing below the IP layer. An opportunistic multiple media access control aggregation (OMMA) layer may reside between the IP layer and the RAT protocol stacks. The OMMA layer may include an OMMA scheduler that may distribute incoming IP data packets among the RAT protocol stacks. An OMMA controller may communicate a control parameter to the OMMA scheduler for selecting a RAT protocol stack for distributing an incoming IP data packet. A wireless transmit/receive unit RAT capability database may store RAT capability information. A policy database may store a policy for distributing the IP data packets among the RAT protocol stacks.

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CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/603,004, filed February 24, 2012; and U.S. Provisional Patent Application No. 61/676,121, filed on July 26, 2012; and U.S Provisional Patent Application No. 61/678,060 filed July 31, 2012; the contents of which are hereby incorporated by reference herein.

BACKGROUND

[0002] Wireless technologies have been demanding higher data throughput rates and lower latencies. The use of carrier aggregation and multi-radio access technology (RAT) capabilities has been introduced. Carrier aggregation may allow operators to offload some of their data traffic to secondary cells (*e.g.*, transmitted on secondary component carriers). In multi-RAT systems reception and/or transmission may be performed over multiple RATs. For example, a network terminal (NT) (*e.g.*, an access point (AP), an eNodeB (eNB), Homes eNbs (HeNbs), *etc.*) and a wireless transmit/receive unit (WTRU) (*e.g.*, a user equipment (UE), a station (STA), *etc.*) may communicate over multiple parallel paths. However, each RAT may be used for only one Internet Protocol (IP) flow. There are many problems associated with such communication.

SUMMARY

[0003] Systems, methods, and instrumentalities are disclosed to manage multiple radio access technology (RAT) interfaces to enable opportunistic RAT selection and aggregation for sending data traffic over the RAT interfaces. A device may include an Opportunistic Multiple-Medium Access Control (MAC) Aggregation (OMMA) layer that resides below the IP layer but above the RAT protocol stacks and includes control plane and data plane processing capability.

[0004] A node (*e.g.*, a WTRU or NT) in communication with a wireless communication system may comprise a processor that is in operable communication with a plurality of radio access technologies (RATs). The processor may be configured to receive first feedback

information associated with a first RAT and receive second feedback information associated with a second RAT. The processor may be configured to determine a first IP packet to send via the first RAT according to the first and second feedback information and determine a second IP packet to send via the second RAT according to the first and second feedback information. The first and second IP packets may be part of an Internet Protocol (IP) flow addressed to a receiving node. The processor may send the first IP packet via the first RAT and may send the second IP packet via the second RAT.

[0005] The processor of the node may be further configured to perform a hybrid packet distribution method. For example, the processor may be configured to determine whether channel quality of the first RAT and/or the second RAT is below a threshold. Upon determining that channel quality of the first RAT is below the threshold, the processor may be configured to duplicate the first IP packet to create a first instance of the first IP packet and a second instance of the first IP packet. The processor may be configured to send the first instance of the first IP packet via the first RAT and send the second instance of the first IP packet via a third RAT. Upon determining that channel quality of the second RAT is at or above the threshold, the processor may be configured to send the second IP packet via the second RAT.

[0006] A method (*e.g.*, performed by a WTRU or a NT comprising an OMMA layer) may aggregate the bandwidth available on multiple radio access technologies (RATs). The method may comprise assigning a first variable to a first RAT and a second variable to a second RAT. The method may increment the first variable of the first RAT by a first rate and increment the second variable of the second RAT by a second rate. The first rate may be related to an estimated arrival rate of a packet transmitted across the first RAT, and the second rate may be related to an estimated arrival rate of a packet transmitted across the second RAT. The method may comprise determining whether the first variable is greater than or equal to a threshold value. Upon determining that the first variable is greater than or equal to the threshold value and that the second variable is less than the threshold value, the method may send a packet across the first RAT. The method may then decrease the first variable by the threshold value.

[0007] A node (*e.g.*, a WTRU or a NT) may comprise an opportunistic multiple radio access technologies (RAT) aggregation (OMMA) layer. The OMMA layer may comprise a controller and a scheduler, the controller and scheduler may be in operable communication with a first radio access technology (RAT) and a second RAT. The controller may be configured to determine a first time duration and a first bandwidth requirement for a first IP packet, and determine a second time duration and a second bandwidth requirement for a second IP packet. The first IP packet and the second IP packet may be part of an IP flow addressed to a receiving

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node. The controller may be configured to request resources on the first RAT and the second RAT based on the first time duration and the first bandwidth requirement for the first IP packet and based on the second time duration and second bandwidth requirement for the second IP packet. The controller may be configured to send instructions to a scheduler. The scheduler may be configured to receive first feedback information associated with the first RAT, and receive second feedback information associated with the second RAT. The scheduler may be configured to determine to send the first IP packet via the first RAT according to the first and second feedback information and the instructions, and to determine to send the second IP packet via the second RAT according to the first and second feedback information and the instructions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1A is a system diagram of an example communications system in which one or more disclosed embodiments may be implemented.

[0009] FIG. 1B is a system diagram of an example wireless transmit/receive unit (WTRU) that may be used within the communications system illustrated in FIG. 1A.

[0010] FIG. 1C is a system diagram of an example radio access network and an example core network that may be used within the communications system illustrated in FIG. 1A.

[0011] FIG. 1D is a system diagram of an another example radio access network and another example core network that may be used within the communications system illustrated in FIG. 1A.

[0012] FIG. 1E is a system diagram of an another example radio access network and another example core network that may be used within the communications system illustrated in FIG. 1A.

[0013] FIG. 2 is an example system architecture of a base station system infrastructure.

[0014] FIG. 3 is an example system of a NT with capability to support multiple RATs.

[0015] FIG. 4 is a diagram illustrating an example of multi-RAT aggregation using an OMMA layer.

[0016] FIG. 5 is a diagram illustrating an example of dual-RAT aggregation with a common OMMA layer residing above a MAC.

[0017] FIG. 6 is a block diagram of an example OMMA layer.

[0018] FIG. 7 is a table illustrating an example of parameters that may be signaled when a NT advertises its RAT capabilities using a management signal.

[0019] FIG. 8 is a diagram illustrating an example of an active scanning procedure.

[0020] FIG. 9 is a diagram illustrating an example of an passive scanning procedure.

[0021] FIG. 10 is a diagram illustrating an example of diversity mode.

[0022] FIG. 11 is a diagram illustrating an example of multiplexing mode.

[0023] FIG. 12 is a diagram illustrating an example of hybrid mode.

[0024] FIG. 13 is a diagram illustrating an example of dynamic RAT switching mode.

[0025] FIG. 14 is a diagram illustrating an example timeline for transmitting feedback metrics.

[0026] FIG. 15 is a diagram illustrating an example message sequence where an OMMA requests measurement metrics for each RAT.

[0027] FIG. 16 is an example message sequence where RAT modules report metrics periodically or aperiodcially to an OMMA module.

[0028] FIG. 17 is a diagram illustrating an example of state and state transition triggers of an OMMA layer.

[0029] FIG. 18 is a diagram illustrating an example of a TCP session.

[0030] FIG. 19 is a diagram illustrating an example of aggregation performed for TCP data.

[0031] FIG. 20 is a diagram illustrating an example architecture of a solution.

[0032] FIG. 21 is a diagram illustrating an example processing of a solution.

[0033] FIG. 22 is a diagram illustrating an example header of a solution.

[0034] FIG. 23 is a diagram illustrating an example of how OMMA may route packets.

[0035] FIG. 24 is a diagram illustrating an example of a table maintained by OMMA.

[0036] FIG. 25 is a diagram illustrating an example of logic used when there is a packet to be scheduled.

[0037] FIG. 26 is a diagram illustrating an example of UDP logic.

[0038] FIG. 27 is a diagram illustrating an example of TCP logic.

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[0039] FIG. 28 is a functional block diagram that depicts an example implementation of an OMMA layer according to an embodiment.

[0040] FIG. 29 is a functional block diagram that depicts an example implementation of an OMMA Controller.

[0041] FIG. 30 is a functional block diagram illustrating one example implementation of an OMMA Scheduler.

[0042] FIG. 31 is a call flow diagram that illustrates an example call flow showing signaling corresponding to a process for RAT availability determination.

[0043] FIG. 32 is a system diagram illustrating data flow in an example scenario of an OMMA sender in which both PBS and FBS are enabled at a NT for single RAT selection for single WTRU single IP flow.

[0044] FIG. 33 illustrates a call flow for the example scenario of FIG. 32.

[0045] FIG. 34 is a functional block diagram illustrating an example transparent OMMA Receiver for single RAT enabled, single WTRU, single IP flow.

[0046] FIG. 35 is a functional block diagram illustrating an example OMMA receiver performing reassembly on a selected RAT.

[0047] FIG. 36 depicts an example call flow for allocating wireless resources for medium access by a NT and WTRUs using a RAT.

[0048] FIG. 37 illustrates an example interface between an OMMA Controller and a WTRU RAT Capability Database.

[0049] FIG. 38 illustrates an example interface between an OMMA Controller and a Policy Database.

[0050] FIG. 39 illustrates an example interface between an OMMA Controller and an OMMA Scheduler.

[0051] FIG. 40 illustrates an example matrix for signaling parameters.

[0052] FIG. 41 illustrates an example matrix for signaling parameters.

[0053] FIG. 42 illustrates an example matrix for signaling parameters.

[0054] FIG. 43 illustrates an example interface between an OMMA Controller and a RAT protocol stack.

[0055] FIG. 44 illustrates example feedback metrics that may be sent by RATs.

[0056] FIG. 45 is a functional block diagram depicting an example interface between an OMMA Scheduler and a WTRU RAT Capability Database.

[0057] FIG. 46 is a functional block diagram depicting an example interface between an OMMA Scheduler and a Policy Database.

[0058] FIG. 47 is a functional block diagram illustrating an example interface between PBS and FBS modules.

[0059] FIG. 48 is a functional block diagram depicting an example interface between an IP Packet QoS Identifier module and a PBS or FBS module within an OMMA Scheduler.

[0060] FIG. 49 is a functional block diagram illustrating an example implementation of an Ax interface between a Policy Database and a DNS-APP entity.

[0061] FIG. 50 is a functional block diagram illustrating an example implementation of an Ay interface between the Policy Database and a user interface application (UI-APP) entity.

[0062] FIG. 51 is a diagram illustrating an example of Multi-RAT Aggregation using OMMA Layer.

[0063] FIG. 52 is a diagram illustrating an example of a threshold for mode selection in two RAT systems.

[0064] FIG. 53 is a diagram illustrating and examples of a packet reordering scenario.

[0065] FIG. 54 is a diagram illustrating and examples of a packet reordering scenario.

[0066] FIG. 55a is a diagram illustrating a random assignment of packets;

[0067] FIG. 55b is a diagram illustrating a smart assignment of packets across RATs.

[0068] FIG. 56 is a representation of an example OMMA smart packet allocation algorithm.

[0069] FIG. 57 is a graph illustrating an example of measurements of average reordering delay per packet for different scheduling schemes.

[0070] FIG. 58 is a diagram illustrating an example of an OMMA Sender at a NT for single RAT selection for Multi WTRU Multi IP Flow.

[0071] FIG. 59 is a diagram illustrating an example call flow.

DETAILED DESCRIPTION

[0072] A detailed description of illustrative embodiments will now be described with

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reference to the various Figures. Although this description provides a detailed example of possible implementations, it should be noted that the details are intended to be exemplary and in no way limit the scope of the application.

[0073] FIG. 1A is a diagram of an example communications system 100 in which one or more disclosed embodiments may be implemented. The communications system 100 may be a multiple access system that provides content, such as voice, data, video, messaging, broadcast, *etc.*, to multiple wireless users. The communications system 100 may enable multiple wireless users to access such content through the sharing of system resources, including wireless bandwidth. For example, the communications systems 100 may employ one or more channel access methods, such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), and the like.

[0074] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, and/or 102d (which generally or collectively may be referred to as WTRU 102), a radio access network (RAN) 103/104/105, a core network 106/107/109, a public switched telephone network (PSTN) 108, the Internet 110, and other networks 112, though it will be appreciated that the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs 102a, 102b, 102c, 102d may be any type of device configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs 102a, 102b, 102c, 102d may be configured to transmit and/or receive wireless signals and may include user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, consumer electronics, and the like.

[0075] The communications systems 100 may also include a base station 114a and a base station 114b. Each of the base stations 114a, 114b may be any type of device configured to wirelessly interface with at least one of the WTRUs 102a, 102b, 102c, 102d to facilitate access to one or more communication networks, such as the core network 106/107/109, the Internet 110, and/or the networks 112. By way of example, the base stations 114a, 114b may be a base transceiver station (BTS), a Node-B, an eNode B, a Home Node B, a Home eNode B, a site controller, an access point (AP), a wireless router, and the like. While the base stations 114a, 114b are each depicted as a single element, it will be appreciated that the base stations 114a, 114b may include any number of interconnected base stations and/or network elements.

[0076] The base station 114a may be part of the RAN 103/104/105, which may also include other base stations and/or network elements (not shown), such as a base station controller (BSC), a radio network controller (RNC), relay nodes, *etc.* The base station 114a and/or the base station 114b may be configured to transmit and/or receive wireless signals within a particular geographic region, which may be referred to as a cell (not shown). The cell may further be divided into cell sectors. For example, the cell associated with the base station 114a may be divided into three sectors. Thus, in one embodiment, the base station 114a may include three transceivers, *e.g.*, one for each sector of the cell. In another embodiment, the base station 114a may employ multiple-input multiple output (MIMO) technology and, therefore, may utilize multiple transceivers for each sector of the cell.

[0077] The base stations 114a, 114b may communicate with one or more of the WTRUs 102a, 102b, 102c, 102d over an air interface 115/116/117, which may be any suitable wireless communication link (*e.g.*, radio frequency (RF), microwave, infrared (IR), ultraviolet (UV), visible light, *etc.*). The air interface 115/116/117 may be established using any suitable radio access technology (RAT).

[0078] More specifically, as noted above, the communications system 100 may be a multiple access system and may employ one or more channel access schemes, such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA, and the like. For example, the base station 114a in the RAN 103/104/105 and the WTRUs 102a, 102b, 102c may implement a radio technology such as Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (UTRA), which may establish the air interface 115/116/117 using wideband CDMA (WCDMA). WCDMA may include communication protocols such as High-Speed Packet Access (HSPA) and/or Evolved HSPA (HSPA+). HSPA may include High-Speed Downlink Packet Access (HSDPA) and/or High-Speed Uplink Packet Access (HSUPA).

[0079] In another embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement a radio technology such as Evolved UMTS Terrestrial Radio Access (E-UTRA), which may establish the air interface 115/116/117 using Long Term Evolution (LTE) and/or LTE-Advanced (LTE-A).

[0080] In other embodiments, the base station 114a and the WTRUs 102a, 102b, 102c may implement radio technologies such as IEEE 802.16 (*e.g.*, Worldwide Interoperability for Microwave Access (WiMAX)), CDMA2000, CDMA2000 1X, CDMA2000 EV-DO, Interim Standard 2000 (IS-2000), Interim Standard 95 (IS-95), Interim Standard 856 (IS-856), Global System for Mobile communications (GSM), Enhanced Data rates for GSM Evolution (EDGE), GSM EDGE (GERAN), and the like.

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[0081] The base station 114b in FIG. 1A may be a wireless router, Home Node B, Home eNode B, or access point, for example, and may utilize any suitable RAT for facilitating wireless connectivity in a localized area, such as a place of business, a home, a vehicle, a campus, and the like. In one embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.11 to establish a wireless local area network (WLAN). In another embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.15 to establish a wireless personal area network (WPAN). In yet another embodiment, the base station 114b and the WTRUs 102c, 102d may utilize a cellular-based RAT (*e.g.*, WCDMA, CDMA2000, GSM, LTE, LTE-A, *etc.*) to establish a picocell or femtocell. As shown in FIG. 1A, the base station 114b may have a direct connection to the Internet 110. Thus, the base station 114b may not be required to access the Internet 110 via the core network 106/107/109.

[0082] The RAN 103/104/105 may be in communication with the core network 106/107/109, which may be any type of network configured to provide voice, data, applications, and/or voice over internet protocol (VoIP) services to one or more of the WTRUs 102a, 102b, 102c, 102d. For example, the core network 106/107/109 may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, *etc.*, and/or perform high-level security functions, such as user authentication. Although not shown in FIG. 1A, it will be appreciated that the RAN 103/104/105 and/or the core network 106/107/109 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 103/104/105 or a different RAT. For example, in addition to being connected to the RAN 103/104/105, which may be utilizing an E-UTRA radio technology, the core network 106/107/109 may also be in communication with another RAN (not shown) employing a GSM radio technology.

[0083] The core network 106/107/109 may also serve as a gateway for the WTRUs 102a, 102b, 102c, 102d to access the PSTN 108, the Internet 110, and/or other networks 112. The PSTN 108 may include circuit-switched telephone networks that provide plain old telephone service (POTS). The Internet 110 may include a global system of interconnected computer networks and devices that use common communication protocols, such as the transmission control protocol (TCP), user datagram protocol (UDP) and the internet protocol (IP) in the TCP/IP internet protocol suite. The networks 112 may include wired or wireless communications networks owned and/or operated by other service providers. For example, the networks 112 may include another core network connected to one or more RANs, which may employ the same RAT as the RAN 103/104/105 or a different RAT.

[0084] Some or all of the WTRUs 102a, 102b, 102c, 102d in the communications system 100 may include multi-mode capabilities, *e.g.*, the WTRUs 102a, 102b, 102c, 102d may include multiple transceivers for communicating with different wireless networks over different wireless links. For example, the WTRU 102c shown in FIG. 1A may be configured to communicate with the base station 114a, which may employ a cellular-based radio technology, and with the base station 114b, which may employ an IEEE 802 radio technology.

[0085] FIG. 1B is a system diagram of an example WTRU 102. As shown in FIG. 1B, the WTRU 102 may include a processor 118, a transceiver 120, a transmit/receive element 122, a speaker/microphone 124, a keypad 126, a display/touchpad 128, non-removable memory 130, removable memory 132, a power source 134, a global positioning system (GPS) chipset 136, and other peripherals 138. It will be appreciated that the WTRU 102 may include any sub-combination of the foregoing elements while remaining consistent with an embodiment. Also, embodiments contemplate that the base stations 114a and 114b, and/or the nodes that base stations 114a and 114b may represent, such as but not limited to transceiver station (BTS), a Node-B, a site controller, an access point (AP), a home node-B, an evolved home node-B (eNodeB), a home evolved node-B (HeNB), a home evolved node-B gateway, and proxy nodes, among others, may include some or all of the elements depicted in FIG. 1B and described herein.

[0086] The processor 118 may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Array (FPGAs) circuits, any other type of integrated circuit (IC), a state machine, and the like. The processor 118 may perform signal coding, data processing, power control, input/output processing, and/or any other functionality that enables the WTRU 102 to operate in a wireless environment. The processor 118 may be coupled to the transceiver 120, which may be coupled to the transmit/receive element 122. While FIG. 1B depicts the processor 118 and the transceiver 120 as separate components, it will be appreciated that the processor 118 and the transceiver 120 may be integrated together in an electronic package or chip.

[0087] The transmit/receive element 122 may be configured to transmit signals to, or receive signals from, a base station (*e.g.*, the base station 114a) over the air interface 115/116/117. For example, in one embodiment, the transmit/receive element 122 may be an antenna configured to transmit and/or receive RF signals. In another embodiment, the transmit/receive element 122 may be an emitter/detector configured to transmit and/or receive IR, UV, or visible light signals, for example. In yet another embodiment, the transmit/receive

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element 122 may be configured to transmit and receive both RF and light signals. It will be appreciated that the transmit/receive element 122 may be configured to transmit and/or receive any combination of wireless signals.

[0088] In addition, although the transmit/receive element 122 is depicted in FIG. 1B as a single element, the WTRU 102 may include any number of transmit/receive elements 122. More specifically, the WTRU 102 may employ MIMO technology. Thus, in one embodiment, the WTRU 102 may include two or more transmit/receive elements 122 (*e.g.*, multiple antennas) for transmitting and receiving wireless signals over the air interface 115/116/117.

[0089] The transceiver 120 may be configured to modulate the signals that are to be transmitted by the transmit/receive element 122 and to demodulate the signals that are received by the transmit/receive element 122. As noted above, the WTRU 102 may have multi-mode capabilities. Thus, the transceiver 120 may include multiple transceivers for enabling the WTRU 102 to communicate via multiple RATs, such as UTRA and IEEE 802.11, for example.

[0090] The processor 118 of the WTRU 102 may be coupled to, and may receive user input data from, the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128 (*e.g.*, a liquid crystal display (LCD) display unit or organic light-emitting diode (OLED) display unit). The processor 118 may also output user data to the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128. In addition, the processor 118 may access information from, and store data in, any type of suitable memory, such as the non-removable memory 130 and/or the removable memory 132. The non-removable memory 130 may include random-access memory (RAM), read-only memory (ROM), a hard disk, or any other type of memory storage device. The removable memory 132 may include a subscriber identity module (SIM) card, a memory stick, a secure digital (SD) memory card, and the like. In other embodiments, the processor 118 may access information from, and store data in, memory that is not physically located on the WTRU 102, such as on a server or a home computer (not shown).

[0091] The processor 118 may receive power from the power source 134, and may be configured to distribute and/or control the power to the other components in the WTRU 102. The power source 134 may be any suitable device for powering the WTRU 102. For example, the power source 134 may include one or more dry cell batteries (*e.g.*, nickel-cadmium (NiCd), nickel-zinc (NiZn), nickel metal hydride (NiMH), lithium-ion (Li-ion), *etc.*), solar cells, fuel cells, and the like.

[0092] The processor 118 may also be coupled to the GPS chipset 136, which may be configured to provide location information (*e.g.*, longitude and latitude) regarding the current location of the WTRU 102. In addition to, or in lieu of, the information from the GPS chipset

136, the WTRU 102 may receive location information over the air interface 115/116/117 from a base station (*e.g.*, base stations 114a, 114b) and/or determine its location based on the timing of the signals being received from two or more nearby base stations. It will be appreciated that the WTRU 102 may acquire location information by way of any suitable location-determination method while remaining consistent with an embodiment.

[0093] The processor 118 may further be coupled to other peripherals 138, which may include one or more software and/or hardware modules that provide additional features, functionality and/or wired or wireless connectivity. For example, the peripherals 138 may include an accelerometer, an e-compass, a satellite transceiver, a digital camera (for photographs or video), a universal serial bus (USB) port, a vibration device, a television transceiver, a hands free headset, a Bluetooth® module, a frequency modulated (FM) radio unit, a digital music player, a media player, a video game player module, an Internet browser, and the like.

[0094] FIG. 1C is a system diagram of the RAN 103 and the core network 106 according to an embodiment. As noted above, the RAN 103 may employ a UTRA radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 115. The RAN 103 may also be in communication with the core network 106. As shown in FIG. 1C, the RAN 103 may include Node-Bs 140a, 140b, 140c, which may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 115. The Node-Bs 140a, 140b, 140c may each be associated with a particular cell (not shown) within the RAN 103. The RAN 103 may also include RNCs 142a, 142b. It will be appreciated that the RAN 103 may include any number of Node-Bs and RNCs while remaining consistent with an embodiment.

[0095] As shown in FIG. 1C, the Node-Bs 140a, 140b may be in communication with the RNC 142a. Additionally, the Node-B 140c may be in communication with the RNC142b. The Node-Bs 140a, 140b, 140c may communicate with the respective RNCs 142a, 142b via an Iub interface. The RNCs 142a, 142b may be in communication with one another via an Iur interface. Each of the RNCs 142a, 142b may be configured to control the respective Node-Bs 140a, 140b, 140c to which it is connected. In addition, each of the RNCs 142a, 142b may be configured to carry out or support other functionality, such as outer loop power control, load control, admission control, packet scheduling, handover control, macrodiversity, security functions, data encryption, and the like.

[0096] The core network 106 shown in FIG. 1C may include a media gateway (MGW) 144, a mobile switching center (MSC) 146, a serving GPRS support node (SGSN) 148, and/or a gateway GPRS support node (GGSN) 150. While each of the foregoing elements are depicted as

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part of the core network 106, it will be appreciated that any one of these elements may be owned and/or operated by an entity other than the core network operator.

[0097] The RNC 142a in the RAN 103 may be connected to the MSC 146 in the core network 106 via an IuCS interface. The MSC 146 may be connected to the MGW 144. The MSC 146 and the MGW 144 may provide the WTRUs 102a, 102b, 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, 102c and traditional land-line communications devices.

[0098] The RNC 142a in the RAN 103 may also be connected to the SGSN 148 in the core network 106 via an IuPS interface. The SGSN 148 may be connected to the GGSN 150. The SGSN 148 and the GGSN 150 may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between and the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0099] As noted above, the core network 106 may also be connected to the networks 112, which may include other wired or wireless networks that are owned and/or operated by other service providers.

[0100] FIG. 1D is a system diagram of the RAN 104 and the core network 107 according to an embodiment. As noted above, the RAN 104 may employ an E-UTRA radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. The RAN 104 may also be in communication with the core network 107.

[0101] The RAN 104 may include eNode-Bs 160a, 160b, 160c, though it will be appreciated that the RAN 104 may include any number of eNode-Bs while remaining consistent with an embodiment. The eNode-Bs 160a, 160b, 160c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In one embodiment, the eNode-Bs 160a, 160b, 160c may implement MIMO technology. Thus, the eNode-B 160a, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU 102a.

[0102] Each of the eNode-Bs 160a, 160b, 160c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the uplink and/or downlink, and the like. As shown in FIG. 1D, the eNode-Bs 160a, 160b, 160c may communicate with one another over an X2 interface.

[0103] The core network 107 shown in FIG. 1D may include a mobility management gateway (MME) 162, a serving gateway 164, and a packet data network (PDN) gateway 166. While each of the foregoing elements are depicted as part of the core network 107, it will be

appreciated that any one of these elements may be owned and/or operated by an entity other than the core network operator.

[0104] The MME 162 may be connected to each of the eNode-Bs 160a, 160b, 160c in the RAN 104 via an S1 interface and may serve as a control node. For example, the MME 162 may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, bearer activation/deactivation, selecting a particular serving gateway during an initial attach of the WTRUs 102a, 102b, 102c, and the like. The MME 162 may also provide a control plane function for switching between the RAN 104 and other RANs (not shown) that employ other radio technologies, such as GSM or WCDMA.

[0105] The serving gateway 164 may be connected to each of the eNode-Bs 160a, 160b, 160c in the RAN 104 via the S1 interface. The serving gateway 164 may generally route and forward user data packets to/from the WTRUs 102a, 102b, 102c. The serving gateway 164 may also perform other functions, such as anchoring user planes during inter-eNode B handovers, triggering paging when downlink data is available for the WTRUs 102a, 102b, 102c, managing and storing contexts of the WTRUs 102a, 102b, 102c, and the like.

[0106] The serving gateway 164 may also be connected to the PDN gateway 166, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0107] The core network 107 may facilitate communications with other networks. For example, the core network 107 may provide the WTRUs 102a, 102b, 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, 102c and traditional land-line communications devices. For example, the core network 107 may include, or may communicate with, an IP gateway (*e.g.*, an IP multimedia subsystem (IMS) server) that serves as an interface between the core network 107 and the PSTN 108. In addition, the core network 107 may provide the WTRUs 102a, 102b, 102c with access to the networks 112, which may include other wired or wireless networks that are owned and/or operated by other service providers.

[0108] FIG. 1E is a system diagram of the RAN 105 and the core network 109 according to an embodiment. The RAN 105 may be an access service network (ASN) that employs IEEE 802.16 radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 117. As will be further discussed below, the communication links between the different functional entities of the WTRUs 102a, 102b, 102c, the RAN 105, and the core network 109 may be defined as reference points.

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[0109] As shown in FIG. 1E, the RAN 105 may include base stations 180a, 180b, 180c, and an ASN gateway 182, though it will be appreciated that the RAN 105 may include any number of base stations and ASN gateways while remaining consistent with an embodiment. The base stations 180a, 180b, 180c may each be associated with a particular cell (not shown) in the RAN 105 and may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 117. In one embodiment, the base stations 180a, 180b, 180c may implement MIMO technology. Thus, the base station 180a, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU 102a. The base stations 180a, 180b, 180c may also provide mobility management functions, such as handoff triggering, tunnel establishment, radio resource management, traffic classification, quality of service (QoS) policy enforcement, and the like. The ASN gateway 182 may serve as a traffic aggregation point and may be responsible for paging, caching of subscriber profiles, routing to the core network 109, and the like.

[0110] The air interface 117 between the WTRUs 102a, 102b, 102c and the RAN 105 may be defined as an R1 reference point that implements the IEEE 802.16 specification. In addition, each of the WTRUs 102a, 102b, 102c may establish a logical interface (not shown) with the core network 109. The logical interface between the WTRUs 102a, 102b, 102c and the core network 109 may be defined as an R2 reference point, which may be used for authentication, authorization, IP host configuration management, and/or mobility management.

[0111] The communication link between each of the base stations 180a, 180b, 180c may be defined as an R8 reference point that includes protocols for facilitating WTRU handovers and the transfer of data between base stations. The communication link between the base stations 180a, 180b, 180c and the ASN gateway 182 may be defined as an R6 reference point. The R6 reference point may include protocols for facilitating mobility management based on mobility events associated with each of the WTRUs 102a, 102b, 102c.

[0112] As shown in FIG. 1E, the RAN 105 may be connected to the core network 109. The communication link between the RAN 105 and the core network 109 may defined as an R3 reference point that includes protocols for facilitating data transfer and mobility management capabilities, for example. The core network 109 may include a mobile IP home agent (MIP-HA) 184, an authentication, authorization, accounting (AAA) server 186, and a gateway 188. While each of the foregoing elements are depicted as part of the core network 109, it will be appreciated that any one of these elements may be owned and/or operated by an entity other than the core network operator.

[0113] The MIP-HA may be responsible for IP address management, and may enable the WTRUs 102a, 102b, 102c to roam between different ASNs and/or different core networks. The MIP-HA 184 may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices. The AAA server 186 may be responsible for user authentication and for supporting user services. The gateway 188 may facilitate interworking with other networks. For example, the gateway 188 may provide the WTRUs 102a, 102b, 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, 102c and traditional land-line communications devices. In addition, the gateway 188 may provide the WTRUs 102a, 102b, 102c with access to the networks 112, which may include other wired or wireless networks that are owned and/or operated by other service providers.

[0114] Although not shown in FIG. 1E, it will be appreciated that the RAN 105 may be connected to other ASNs and the core network 109 may be connected to other core networks. The communication link between the RAN 105 the other ASNs may be defined as an R4 reference point, which may include protocols for coordinating the mobility of the WTRUs 102a, 102b, 102c between the RAN 105 and the other ASNs. The communication link between the core network 109 and the other core networks may be defined as an R5 reference, which may include protocols for facilitating interworking between home core networks and visited core networks.

[0115] A network terminal (*e.g.*, an access point (AP), an eNodeB (eNB), a Home eNbs (HeNbs), a relay, *etc.*) and a WTRU (*e.g.*, a UE, a STA, *etc.*) may be configured to work in an infrastructure mode or an adhoc mode, for example, in an IEEE 802.11 based Wi-Fi system. As described herein, a NT and/or a WTRU may be referred to as a node. Therefore, a node may refer to a network terminal, a WiFi access point, a WTRU, *etc.*

[0116] In the infrastructure mode, the NT may be the central controller for the system and may act as the gateway to the wired network. The NT may operate using an 802.11 system (*e.g.,* 11a/b/g/n) over a band (*e.g.*, 2.4GHz or 5GHz) when communicating with the WTRU. For example, an 802.11 based system may operate in a time division duplexing (TDD) mode, for example, over a single 20/40MHz channel in the case of industrial scientific medical (ISM) band, or over a single 5/10/20 MHz channel in television white space (TVWS) band (*e.g.*, using contiguous/non-contiguous carrier aggregation).

[0117] A multi-band multi-mode NT may support a WTRU operating over 2.4GHz ISM band using the 802.11n protocol and a WTRU operating over TVWS band. WTRUs operating

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on an ISM band may contend with each other for ISM channel access. WTRUs operating over a TVWS band may contend with each other for TVWS channel access. WTRUs operating over an ISM band and WTRUs operating over a TVWS band may not contend with each other, for example, since they are on different operating frequencies. A WTRU may be able to communicate (*e.g.,* simultaneously) with a NT over, for example, an ISM channel and a TVWS channel.

[0118] The NT and WTRU may communicate with each other over a single radio frequency (RF) spectral band, for example, 2.4GHz ISM band, or 5 GHz ISM band, or TVWS band or 60GHz band, using a channel within the band or aggregating multiple contiguous or non-contiguous channels. A WTRU and NT may be multi-band and/or multi-RAT capable devices. A WTRU may support multiple internet protocol (IP) streams, for example, with a different QoS requirement per packet. A WTRU may select a RAT to communicate over the air interface with the other WTRU or NT.

[0119] The medium access delay per channel may be high due to contention among WTRUs, for example, due to a high number of devices crowding each spectral band. The transmit opportunity per WTRU may be small compared to the medium access delay, which may reduce the effective throughput on each channel. A device using a single RAT at a time may experience high latencies, which may impact IP QoS requirements.

[0120] A mechanism to aggregate two or more RATs operating independently on two or more bands to enhance the total IP throughput of the link may be described herein. For example, a single thin software layer (*e.g.*, an opportunistic multi-medium access control (MAC) aggregation (OMMA) layer) may be described herein. For example, the single thin software layer may reside above the medium access control (MAC) layers of the protocol stacks but below the IP layer. For example, the single thin software layer may enable one RAT to operate over industrial scientific medical (ISM) and another RAT to operate over a TVWS band for the same IP flow. This may allow for enhanced throughput and reduced latency for a single IP flow.

[0121] In an IEEE 802.11 based Wi-Fi system, the NT and/or a WTRU may be configured to work in the infrastructure mode of the adhoc mode. FIG. 2 is a diagram illustrating an example system 200 architecture of a base station system infrastructure. In the infrastructure mode, for example, as illustrated in FIG. 2, a NT 201 may be the central controller for the system and act as the gateway to the wired network. The system 200 may comprise one or more WTRUs 202, which may operate utilizing one or more different RATs. The NT 201 may operate using one flavor of the 802.11 system (*e.g.*, 11a/b/g/n) at any given time over a specific band (*e.g.*, 2.4GHz or 5GHz) when communicating with a WTRU. An 802.11 based

system may operate in a time division duplexing (TDD) mode, for example, on a band over a single 20/40MHz channel in the case of ISM band or a single 5/10/20 MHz channel in television white space (TVWS) band using contiguous/non-contiguous carrier aggregation.

[0122] An aggregation layer, which may be referred to an opportunistic multi-medium access control (MAC) aggregation (OMMA) layer, and may be common to all RATs in a NT 201 and/or WTRU 202 may be proposed. The OMMA layer (*e.g.*, or OMMA module) may reside below the IP layer and above the radio protocol stacks. The OMMA layer may not be an independent layer, but rather the functionality of the OMMA layer may reside partially on one or more layers (*e.g.*, the IP layer, the MAC layer, *etc.*) of the protocol stack. Functionality (*e.g.*, or modules) of the OMMA layer may reside on one or more NTs, for example, to allow the processing of the OMMA layer to be divided between network elements.

[0123] As described herein, the OMMA layer may receive meta-data/link statistics feedback (*e.g.*, feedback information) from a RAT (*e.g.*, each RAT). For example, feedback information/statistics may include, but are not limited to, a medium access delay, a frame error rate, an average data rate, a received signal strength indication (RSSI), queuing latency per access category per RAT, end-to-end latency, a backoff time, a number of channels, channel bandwidth, a media access control (MAC) type, MAC aggregation support, an access category, a transmission opportunity (TXOP) duration, an estimated arrival rate of a packet, an average serving rate, an average serving latency, a second moment of average serving latency, an average vacation time, a second average of vacation time, TCP parameters, such as sequence number, acknowledgement number, and window size, for example, *etc.* The statistics may be provided by each RAT.

[0124] The OMMA layer may comprise an OMMA scheduler. The OMMA scheduler may be responsible for traffic shaping, which, for example, may include policy based routing of IP packets across bands or feedback based routing of packets across bands.

[0125] The OMMA layer may comprise a MAC resource reservation mechanism. The MAC resource reservation mechanism may be responsible for requesting a specific amount of time or frequency resources on the medium per channel.

[0126] The OMMA layer may be transparent. If the OMMA layer is transparent, then the OMMA layer may distribute/combine packets from different RATs and forward the packets to the IP layer. The OMMA layer may be non-transparent. If the OMMA layer is non-transparent, then the OMMA layer may add one or more additional headers to an IP packet at the transmitter and read and/or remove the headers at the receiver. The OMMA layer may utilize a

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packet distribution mode. For example, the packet distribution mode may be a diversity mode, a multiplexing mode, a hybrid mode, or a dynamic RAT selection mode.

[0127] Beacons, probe request/response, and/or association request/response frames may be updated by the OMMA layer to include OMMA device discovery parameters, for example, such as but not limited to OMMA modes, OMMA schemes, OMMA packet distribution modes, *etc.*

[0128] Supporting an OMMA layer may cause TCP reordering issues, for example, in case the transport layer used is TCP, since packet distribution across RATs may imply an out-of-order reception of packets at the receiver. Reordering of packets at the receiver may trigger detection of a congestion event at the sender TCP, which may subsequently decide to throttle the throughput. Solutions to solve these problems utilizing the OMMA layer may be described herein.

[0129] A system may comprise a NT with the capability to support multiple Radio Access Technologies (RATs), where each RAT may be operating on one or more spectral bands. FIG. 3 is a diagram illustrating an example system 300 of a NT with capability to support multiple RATs. The NT 301 may be operable to communicate with WTRUs 302 that do not comprise an OMMA layer, and WTRUs 315 that do comprise an OMMA layer. For example, the NT 301 may support an 802.11n based RAT operating on 802.11af, a RAT operating on 512MHz to 698 MHz TVWS band, 2.4 GHz ISM band, 802.11ac RAT operating on 5GHz ISM band, LTE RAT operating on 2 GHz licensed band, WCDMA/HSPA RAT operating on 900 MHz licensed band, *etc.*

[0130] A WTRU 315 in the system 300 may operate on one or more RATs (*e.g.*, those described herein). For example, one or more WTRUs 315 may support 802.11n based RAT operating on 802.11af RAT operating on 512MHz to 698 MHz TVWS band, one or more WTRUs 315 may support 2.4 GHz ISM band, 802.11ac RAT operating on 5GHz ISM band, one or more WTRUs 315 may support LTE RAT operating on 2 GHz licensed band, one or more WTRUs 315 may support WCDMA/HSPA RAT operating on 900 MHz licensed band, *etc.* WTRUs 315 operating on a particular spectral band may contend with each other for wireless medium access.

[0131] A WTRU (*e.g.*, a multi-RAT WTRU) may support more than one RAT. These WTRUs may operate using one RAT at any given time based on an independent decision by the WTRUs or based on decision by the NT they are associated with. A WTRU may operate using a plurality of RATs at any given time based on an independent decision by the WTRUs or based on decision by the NT they are associated with.

[0132] FIG. 4 is a diagram illustrating an example of multi-RAT aggregation using an OMMA layer. A WTRU and/or a NT may comprise an OMMA layer 400. A WTRU or NT that comprises an OMMA layer 400 may support more than one RAT 401. Such a WTRU or NT may include one or more features described herein which may enable the WTRU or NT to operate on a plurality of RATs simultaneously by aggregating data across the RATs. For example, the data may be for a single IP flow. A single IP flow may refer to a stream of IP packets belong to a particular application. For example, a single IP flow may refer to a stream of IP packets that belong to a particular application and share the same 5-tuple. The 5-tuple may be comprised of the following five fields in the IP Header: IP protocol; Source IP address; Destination IP; address; Source Port Number; and Destination Port Number. A WTRU and a NT that comprise an OMMA layer may support multiple RAT connection simultaneously.

[0133] A NT and/or WTRU may comprise one or more modules within the NT and/or WTRU. The modules include, but are not limited to, one or more RATs 401, multiple antenna/radio frequency (RF) front-end pairs 403, a common module between the IP module 402 and the multiple RAT modules 401 (*e.g.*, the OMMA layer 400), *etc.*

[0134] As described herein, a RAT may be, for example, a WiFi RAT, an LTE RAT, a WCDMA/HSPA RAT, an UTRAN RAT, an E-UTRAN RAT, *etc.* A Wi-Fi RAT may be a IEEE802.11n RAT, a IEEE802.11ac RAT, a IEEE802.11af RAT, *etc.* An LTE RAT may be a LTE Rel-8 compliant RAT, a LTE-A Rel-10 compliant RAT, *etc.* A WCDMA RAT may be a WCDMA R4 compliant RAT, a WCDMA/HSDPA/HSUPA Rel6 RAT, *etc.* The OMMA layer may communication with a plurality of RATs, which for example, may comprise any combination of RAT types. For example, an OMMA layer may communicate with a WiFi RAT operating over an industrial, scientific and medical (ISM) radio band and a WiFi RAT operating over a TV white space (TVWS) radio band.

[0135] For multiple RATs 401, each RAT 401 may be operating on a specific band. For example, a 802.11n PHY/MAC operating over 2.4GHz ISM band, a 802.11af PHY/MAC operating over 512MHz – 698 MHz TVWS band, an LTE RAT operating of a licensed band (*e.g.*, 700MHz band), a Bluetooth RAT operating on 2.4GHz ISM band, *etc.*

[0136] For multiple antenna/RF front-end pairs 403, each may be operating on a specific band. For example, one 2.4GHz ISM band radio, one 512MHz – 698 MHz TVWS band split as a low band radio and high band radio, one LTE 700MHZ radio, *etc.*

[0137] The OMMA layer 400 may be a common layer/module between the IP layer/module 402 and the multiple RAT layers/modules 401. As described herein, the OMMA layer/module 400 may allocate IP packets to one or more RATs.

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[0138] FIG. 5 is a diagram illustrating an example of dual-RAT aggregation with a common OMMA layer residing above MAC. FIG. 5 shows an exemplary device (*e.g.*, NT or WTRU) architecture which is aggregating two RATs 501a, 501b, for example, an 802.11n based RAT operating on ISM band and another 802.11 based RAT with non-contiguous carrier aggregation operating on TVWS band. The RATs 501a, 501b may comprise a MAC layer/module 502 and one or more physical layers/modules 503. The OMMA layer 500 may receive meta-data feedback from each of the RATs 501a, 501b. The OMMA layer 500 may decide to split IP packets based on received meta-data. Table 1 may provide the interfaces between an OMMA layer (*e.g.*, OMMA layer 500) and an IP layer (*e.g.*, IP layer 504) and one or more RATs (*e.g.*, RATs 501a, 501b), for example, as shown in FIG. 5.

Table 1

Interface	Description
M1	Meta-data/link statistics from TVWS band protocol stack to thin layer
M2	Meta-data/link statistics from ISM band protocol stack to thin layer
A1	Incoming/Outgoing MAC MSDUs on TVWS band, and MAC resource reservation control signaling
A2	Incoming/Outgoing MAC MSDUs on ISM band, and MAC resource reservation control signaling
S	Incoming/Outgoing IP Packets

[0139] FIG. 6 is a block diagram of an example OMMA layer. The OMMA layer 600 may comprise one or more of the following: a traffic shaping module 601, a MAC resource reservation module 602, and an internet protocol (IP) quality of service (QoS) scheduler 603. The traffic shaping module 601 may responsible for determining the way packets are routed across RATs. For example, the traffic shaping module may determine the way a packet is routed using policy based routing or feedback based routing.

[0140] In policy based routing, the packets may be transmitted on different RATs using one or more rules (*e.g.*, pre-defined rules or policies). The rules may include, but are not limited to, one or more of device capability, an operator policy, a quality of service (QoS) class, an IP packet flow, device coordinates, a source domain, a source IP address, a destination domain, a destination IP address, a port number, a subscriber priority, a link quality, charging, security, the rules/policies described in Table 5, *etc.*

[0141] In feedback based routing, the packets may be transmitted on different RATs using the feedback metrics. The feedback metrics may include, but are not limited to, RSSI, medium access delay, *etc.* The feedback metrics may reflect the average state of the system operating on each RAT.

[0142] The MAC Resource Reservation module 602 may determine an amount of time duration and/or spectral fragment/bandwidth required by a packet or a set of packets. This module may transmit specific requests to the RATs over the A1/A2 interface.

[0143] The IP QoS Scheduler module 603 may segregate a single IP packet stream comprising multiple IP QoS types into distinct IP QoS streams, for example, so that the traffic shaping module 601 may treat each IP QoS stream independently and satisfy the specific QoS requirements when routing the IP packets.

[0144] OMMA device discovery parameters may be described herein. The OMMA system may comprise devices (*e.g.*, NT, WTRU, *etc.*) that support a single RAT or support more than one RAT. Information (*e.g.*, the number of RATs that are supported, the identity of the RATs, *etc.*) may be known to each device so that they may communicate using the highest possible link throughput. In a centralized network, the NT may advertise its RAT capabilities to all the WTRUs in its coverage area so that any new WTRU entering its coverage area may be informed. A WTRU in the coverage area of the NT (*e.g.*, a new WTRU) may inform/advertise its RAT capabilities to the NT so that each NT may negotiate and/or select the appropriate set of RATs to be used for communication between them. FIG. 7 is a table of example parameters that may be signaled when a NT advertises its RAT capabilities using a management signal.

[0145] OMMA RAT selection may be described herein. OMMA devices (*e.g.*, a NT and a WTRU) may discover each utilizing an active scanning procedure or a passive scanning procedure. FIG. 8 is a diagram illustrating an example of an active scanning procedure. In the active scanning procedure, a WTRU may transmit a probe request signal to one or more NTs, for example, as a way to discover the receiving devices. Since these may be multi-RAT devices (*e.g.*, WTRUs and/or NTs) each operating over different spectral bands/channels, the probe request may be transmitted on one or more of the channels. The probe request signal may comprise the OMMA parameters of the device (*e.g.*, WTRU OMMA parameters). Upon receiving the probe request on all or a subset of the RATs that it supports, the NT may transmit a probe response on one or more of the RATs. In the case of OMMA, the NT may transmit its OMMA parameters along with the probe response. Upon reception of the probe response, the WTRU may select one or more of the RATs to perform the authentication with the other device.

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[0146] After the authentication procedure, the WTRU may transmit an association request to the NT, for example, to request membership with the receiving device. The WTRU may use one or more of the RATs for association (*e.g.*, the same RAT that was used for authentication). The authentication request signal may comprise the WTRU's OMMA parameters. The NT may respond with an association response signal accepting or rejecting membership of the WTRU. The association response may comprise a selected list of RATs and/or OMMA parameters for communication (*e.g.*, downlink and/or uplink communication) between the NT and the WTRU.

[0147] FIG. 9 is a diagram illustrating an example of a passive scanning procedure. In the passive scanning procedure, the WTRU may wait for the periodic beacon signal to be transmitted by a NT on one or more of the RATs. Upon receiving a beacon signal, the WTRU may read the contents of the beacon. The NT may transmit its OMMA parameters on all beacon signals so that WTRUs (*e.g.*, new WTRUs) may identify the OMMA capabilities of the NT.

[0148] The WTRU may compare a list of RATs supported by the NT with its own list of RATs supports. The WTRU may then select one or more of the RATs and perform an authentication procedure with the NT over the one or more RATs.

[0149] After the authentication procedure, as in the active scanning case above, the WTRU may transmit an association request to the NT to request membership with the NT. The WTRU may use one or more of the RATs for association (*e.g.*, the same RAT that was used for authentication). The authentication request signal may comprise the WTRU's OMMA parameters. The NT may respond with an association response signal accepting or rejecting membership of the WTRU. The association response may comprise a selected list of RATs and/or the OMMA parameters for communication (*e.g.*, uplink and/or downlink communication) between the NT and the WTRU.

[0150] OMMA packet distribution modes may be described herein. The OMMA layer at the transmitter may distribute packets across multiple RATs using one or more of the following distribution modes: Diversity Mode, Multiplexing Mode, Hybrid Mode, or Dynamic RAT Selection Mode.

[0151] FIG. 10 is a diagram illustrating an example of diversity mode. In diversity mode, IP Packets at the OMMA layer 1000 may be duplicated across multiple RATs 1001 when the instantaneous channel quality at each RAT 1001 is below a lower threshold (*e.g.*, is very low). Diversity mode may enable transmission of an IP packet with a high probability of error-free reception. Diversity mode may be equivalent to the transmit diversity mode in a multiple-input multiple output (MIMO) system.

[0152] FIG. 11 is a diagram illustrating an example of multiplexing mode. In multiplexing mode, when the OMMA layer 1100 determines that the channel quality for one or more RATs 1101 is above an upper threshold (*e.g.*, is very good), the OMMA layer 1100 may transmit different independent IP packets across one or more of the RATs 1101. This way the throughput may be maximized since the probability of the IP packet being received in error on any RAT 1101 is relatively low.

[0153] FIG. 12 is a diagram illustrating an example of hybrid mode. In hybrid mode, when the OMMA layer 1200 under consideration supports multiple RATs 1201, some of which have a poor channel quality (*e.g.*, RATs 1201a, 1201b), while the remaining have a good channel quality (*e.g.*, RATs 1201c, 1201d), for example at a given time, the RATs with a poor channel quality may be used in one mode (*e.g.*, diversity mode), while the RATs with good channel quality could be used in another mode (*e.g.*, multiplexing mode). The determination of poor channel quality and good channel quality may be determined by the OMMA layer 1200 utilizing the lower threshold and upper threshold, respectively.

[0154] FIG. 13 is a diagram illustrating an example of dynamic RAT switching mode. In dynamic RAT switching mode, the OMMA layer 1300 may select the best RAT possible (*e.g.*, RAT 1301a) at any given time and not use the remaining RATs (*e.g.*, RAT 1301b). For example, the OMMA layer 1300 may make this determination based on the instantaneous channel quality/availability of the RATs 1301a, 1301b. As the channel quality/availability of RATs 1301a, 1301b changes, the best RAT may be selected which may be different from the one previously used.

[0155] For example, if the channel quality of one RAT is 6dB or lower than the channel quality of the other RATs, the RAT with the low channel quality may be disabled. If the OMMA layer determines that the ratio of packets distributed across a dual RAT device is 9:1, Dynamic RAT Switching Mode may be enabled, for example, so the RATs with a better channel quality may be used. For example, channel quality events that may trigger this mode may include, but are not limited to, low throughput, low RSSI, transmission control protocol (TCP) re-ordering trigger, high medium access delay, and high end-to-end delay.

[0156] As noted herein, the OMMA layer may determine to send one or more IP packets via one or more RATs. For example, the OMMA layer may determine to send a first IP packet via a first RAT and a second IP packet via a second RAT according to a packet distribution mode. The packet distribution mode may be one of diversity mode, multiplexing mode, hybrid mode, or dynamic RAT selection mode. For example, the OMMA layer may determine that channel quality of the first RAT is below a threshold. The OMMA layer may duplicate the first

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IP packet to create a first instance of the first IP packet and a second instance of the first IP packet. The OMMA layer may send the first instance of the first IP packet via the first RAT and send the second instance of the first IP packet via a third RAT. This may be an example of the OMMA layer operating under diversity mode. The OMMA layer may determine that channel quality of the second RAT is at or above the threshold, and send the second IP packet via the second RAT. This may be an example of the OMMA layer operating under multiplexing mode (*e.g.*, or may be considered hybrid mode when taken into consideration with the first IP packet sent via the first RAT and third RAT).

[0157] OMMA traffic shaping may be described herein. Traffic shaping at the OMMA layer may be done to distribute (*e.g.*, optimally distribute) IP packets across the different RATs, for example, based on the feedback metrics received from each RAT module, which may indicate the quality of the channel of each RAT. Policy based routing or feedback based routing may be used to determine the ratio of distribution of packets between the various RATs.

[0158] Policy based routing may use a predefined set of rules/policies to determine the ratio with which the IP packets may be distributed across RATs. The OMMA layer may determine the IP packet distribution ratio utilizing one or more of device capability, operator/administrator's local policy, and external database/policy server, *etc.*

[0159] For device capability, some of the devices may have a fixed ratio in which they may serve packets across the RATs. For example, this fixed ratio may be stored in the device (*e.g.*, WTRU or NT) memory. The OMMA transmitter may look up an internal memory/database to determine if the receiver OMMA can support such a fixed ratio and distribute the packets accordingly.

[0160] For operator/administrator's local policy, the operator or administrator may define certain policies which may be such that the OMMA transmitter uses certain fixed ratio of packet distribution for each of the receivers. This ratio may change based on the operator/administrator's requirements. For external database/policy server, the OMMA transmitter may look up an external database or policy server to determine the ratio with which IP packets may be distributed to each receiving OMMA device.

[0161] In feedback based routing, the OMMA transmitter may use measurement metrics fed back from each RAT. The measurement metrics may include, but are not limited to, channel quality metrics and the number of available resources on the medium. The OMMA transmitter may utilized the measurement metrics to determine the instantaneous ratio of distribution of packets across the RATs. Table 2 provides examples of feedback metrics that may be used by an OMMA layer (*e.g.*, an OMMA transmitter).

Table 2

Metric	Sender	Description
Medium Access Delay	MAC	Total packet delay in queue plus contention delay
RSSI	PHY	Received signal strength indication from PMD_RSSI.indication (*e.g.*, strength)
Frame error rate	MAC	Average rate at which packets are NACKed
Data rate	MAC	Average throughput
Queuing latency	MAC	Total packet delay in queue
End-to-end delay	MAC	Total delay from input to MAC at transmitter to output of MAC at receiver
TXOP duration	MAC	TXOP duration for video and voice access categories
AC with medium access	MAC	AC_BK, AC_BE, AC_VI, AC_VO, legacy
Backoff time	MAC	Random back off duration
Number of channels	PHY/MAC	Integer number of distinct channels
Channel bandwidth(s)	PHY/MAC	Vector/List of elements which are multiple of 0.5 MHz
MAC Aggregation Supported	MAC	Boolean: Yes, No
MAC Type	MAC	CSMA/CA, OFDMA, *etc.*

[0162] A feedback based OMMA algorithm may be described herein. Examples of how an OMMA layer may be utilized to distribute packets across multiple RATs based on feedback metrics may be described herein. The algorithm may comprise one or more of a cold start phase, a ramp-up phase, and a steady-state phase.

[0163] The cold start phase may be triggered when the device starts an OMMA layer/module for the very first time. In this phase, the OMMA layer may request the individual RATs to transmit the total channel bandwidths supported by them. The OMMA layer may use this information to distribute the IP packets across the RATs accordingly. For example, if two RATs are supported by the device, one operating on ISM band and the other operating on TVWS band, the ratio of packet distribution between the RAT on the ISM band to the RAT on the TVWS band may be determined by the OMMA layer utilizing the following:

$$BW_{ISM} : \sum_{k=1}^{N} BW_{TVWS}^{k}$$

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[0164] In the ramp-up phase, the RSSI metrics may be assumed to have converged and/or may be assumed to be reliable metrics to indicate instantaneous channel quality of each RAT. For example, if two RATs are supported by the device, one operating on ISM band and the other operating on TVWS band, the ratio of packet distribution between the RAT on the ISM band to the RAT on the TVWS band may be determined by the OMMA layer utilizing the following:

$$\left\lceil \frac{avg(RSSI_{ISM})}{\max(RSSI_{ISM})} \times BW_{ISM} \right\rceil : \left\lceil \left[\sum_{k=1}^{N} \frac{avg(RSSI_{TV}^{k})}{\max(RSSI_{TV}^{k})} \right] \times BW_{TVWS}^{k} \right\rceil .$$

[0165] In the steady state phase, the feedback metrics (*e.g.*, all the feedback metrics) from the RATs received by the OMMA layer may be assumed to have converged, and may provide reliable indicators of channel quality, medium access delay, frame error rate, *etc.* For example, if two RATs are supported by the device, one operating on ISM band and the other operating on TVWS band, the ratio of packet distribution between the RAT on the ISM band to the RAT on the TVWS band may be determined by the OMMA layer utilizing one or more of the following. The ratio may be determined to be a function of bandwidth (BW) and frame error rate (FER). For example, the ratio may be determined by the OMMA layer utilizing the following:

$$\left\lceil (1 - FER_{ISM}) \times BW_{ISM} \right\rceil : \left\lceil \left[\sum_{k=1}^{N} (1 - FER_{TVWS}^{k}) \right] \times BW_{TVWS}^{k} \right\rceil .$$

[0166] The ratio may be determined by a function of the average total delay experienced by a packet over each RAT. For example, if two RATs are supported by the device, one operating on ISM band and the other operating on TVWS band, the ratio of packet distribution between the RAT on the ISM band to the RAT on the TVWS band may be determined by the OMMA layer utilizing the following:

$$1/\tau_{ISM} : 1/\tau_{TVWS}$$

where τ_{ISM} and τ_{TVWS} are the average total delay experienced by a packet over ISM and TVWS RATs respectively.

[0167] OMMA multi-RAT metric feedback management may be described herein. FIG. 14 is a diagram illustrating an example timeline for sending feedback metrics. At the transmitter, the feedback metrics from each RAT may be sent with a predetermined timing, for example, as shown in FIG. 14. At startup, the OMMA layer may receive the available bandwidth of each of

the one or more RATs. At the beginning of the ramp-up phase, the OMMA layer may receive RSSI values as seen by the one or more RATs. Following the ramp-up phase, the steady state-phase may start where the RAT modules at the transmitter OMMA layer may report metrics periodically or aperiodically. The metrics may include, but are not limited to, medium access delay, RSSI, queuing delay, *etc.* The receiver OMMA layer may report certain RAT measurement metrics back to the transmitter OMMA layer. The OMMA layer algorithm may process the metrics received and update the ratio of distribution of packets across RATs periodically or aperiodically.

[0168] FIG. 15 is a diagram illustrating an example message sequence where an OMMA layer requests measurement metrics for each RAT. The message sequence in FIG. 15 shows an exemplary sequence where the OMMA layer 1500 at the transmitter may request measurement metrics for each RAT 1502a, 1502b from the OMMA layer 1501 at the receiver. The OMMA layer 1501 at the receiver may respond with the corresponding metric values. The request/response for the measurement metrics may occur on either a subset or all of the RATs supported by the OMMA layer 1502 at the receiver.

[0169] FIG. 16 is a diagram illustrating an example message sequence where RAT modules may report metrics periodically or aperiodcially to an OMMA module. The message sequence 1600 is an example of a sequence where RAT modules 1603 at the transmitter OMMA layer 1601 may report metrics periodically or aperiodically to the receiver OMMA layer 1602. The receiver OMMA layer 1602 may determine the appropriate split based on the feedback metrics and may determine the ratio in which IP packets may be distributed across the RATs 1603.

[0170] FIG. 17 is a diagram illustrating an example of states and state transition triggers of an OMMA layer. Table 3 shows an example event list for OMMA layers.

Table 3

EVENT/STATE TRANSITION TRIGGER	DESCRIPTION	ACTION	INITIAL STATE	FINAL STATE
OMMA_START	Initialization at startup	Transition to IDLE	INIT	IDLE
OMMA_STOP	Reset	Transition to INIT	IDLE	INIT
IP_PKT_ARRIVAL_DL	IP packet arrives from IP module to OMMA	OMMA performs Opportunistic assignment of IP packet to ISM band	IDLE	IDLE

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	module	or TVWS band		
ISM_MSDU_ARRIVAL_UL	MAC MSDU from ISM band arrives at OMMA	OMMA is Transparent; Forwards packet to IP module	IDLE	IDLE
TVWS_MSDU_ARRIVAL_UL	MAC MSDU from TVWS band arrives at OMMA	OMMA is Transparent; Forwards packet to IP module	IDLE	IDLE

[0171] TCP over OMMA may be described herein. TCP IP flows may require some special handling by an OMMA layer. FIG. 18 is a diagram illustrating an example TCP. For example, there may be a single physical transport. The sending TCP entity may transmit six packets. It may be assumed that the interface is somewhat lossy, so one or more of the packets may get dropped and never reach the receiver. For example, packets 1, 2, 3, 5, and 6 may reach the receiver and packet 4 may be dropped. When the receiver senses that there is a missing packet, the receiver may presume that there was congestion on the interface between the sender and the receiver. The receiver may inform the sender of the missing packet. The sender may retransmit the missing packet, and may decide to limit the amount of data is transmits to the receiver, for example, because there is congestion on the link and the best way to reduce congestion is to throttle back how much data is being transmitted. If packets continue to be dropped, this process may continue until the sender is barely transmitting any packets to the receiver. Since TCP may be greedy when it comes to consuming bandwidth, if packets are not dropped, then the sender may keep increasing the amount of packets it transmits until packets are dropped. In this way, TCP may maximize it throughput up to the limits of the link and may have a mechanism to handle when it has reached the limits of the link.

[0172] FIG. 19 is a diagram illustrating an example of aggregation performed for TCP data. For example, it may be assumed that the sender has six packets to transmit to the receiver. The packets may reach the OMMA layer on the sender side, which may decide that the first packet is to be transmitted over 802.11n while the remaining five packets are to be transmitted over the TVWS channels. It may also be assumed that the 802.11n link has a higher latency than the TVWS channels, so that packets two through six may arrive before the first packet. The OMMA layer at the receiving side may push the received packets up the stack. When they reach the receiving TCP entity, it may assume that the first packet was dropped and request the sending side to retransmit. The sending TCP entity may assume that there is congestion on the link, retransmit the missing packet, and enter congestion avoidance. Congestion avoidance may

reduce the amount of packets that will be transmitted. The effect of this is that even though there is no congestion, very little data may be transmitted from the sender TCP entity. Therefore, even though there is more bandwidth available since the OMMA layer aggregation is being utilized, the TCP entity may not attempt to utilize the additional bandwidth since it has sensed congestion. Therefore, the reordering issue may be addressed within the OMMA layer at the sender or the receiver.

[0173] The OMMA layer may interface the TCP layer of the stack to receive some of the internal data of the TCP entity. The OMMA layer may receive information about when the receiving TCP entity is about to signal to the sending TCP entity that is it receiving packets out of order. Upon receipt of this information, the OMMA entities at the sender and receiver may exchange this information and use it in the routing decisions that may be made by the sending OMMA entity. This TCP information may be in addition to any other information that the sending OMMA entity may use to make routing decisions on a packet-by-packet basis. FIG. 20 is a diagram illustrating an example architecture of such a solution. The parameters to be passed from the TCP entities to the OMMA entities may be related to the timers and other parameters that TCP uses to determine if congestion is occurring.

[0174] The OMMA layer may perform packet inspection of the TCP header to deduce the state of the TCP connection. This may need to be performed in both the uplink and downlink directions, therefore, this solution may require the OMMA layer to be cognizant of whether the packet is being sent or received. Therefore, when the OMMA layer at the receiver receives a packet, it may determine if it is a TCP packet or not. If not, then no further processing may be required. If it is a TCP packet, then it may be determined if it is either a transmit packet or a receive packet. After this determination, the required information within the TCP header may be extracted by the OMMA layer. For example, TCP parameters of interest may include, but are not limited to, sequence number, acknowledgement number, and window size. This information may be retained for each specific 5-tuple: source and destination IP address, source and destination port number, and IP protocol, which may be TCP.

[0175] As the transmit and receive packets traverse the OMMA entities, the OMMA layer at the sender may be able to deduce whether or not the receiving entity is receiving all the packets in the proper order for that specific TCP session. This information may then be used by the transmitting OMMA layer as an input to the decision process that determines over which transport to dispatch a packet. FIG. 21 is a diagram illustrating an example processing of such a solution.

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[0176] The OMMA layer at the sender may insert sequence numbers into the packets that are being sent. The OMMA layer at the receiver may reorder the packets based on these sequence numbers before passing them up to the IP layer, and subsequently to the TCP layer. This may ensure that the receiving TCP entity may not receive packets out of order. The receiving OMMA layer may not hold packets forever while it waits for any missing packets. Eventually, the receiving OMMA layer may pass along the packets it has even if there is missing data. Holding packets for extended periods of time may cause the transmitting TCP entity to retransmit these packets since the transmitting TCP entity may not receive any acknowledgements for those packets that are being held within the receiving OMMA layer.

[0177] A header may be added to the information, for example, in response to this addition of sequence numbers. The header may comprise a sequence number and/or a flow ID number, which may be used to restore the proper order to TCP flows within the receiving OMMA layer. The flow ID may be set to zero to indicate when the payload is not a TCP packet and may be set to a unique non-zero number for each IP flow. The OMMA layer at the sender may reuse the same flow ID for all packets associated with the TCP IP flow. FIG. 22 is a diagram illustrating an example header of such a solution.

[0178] When the receiving OMMA layer receives a packet it may remove the OMMA header and route the packet to the IP layer based on the information within the OMMA header. If the flow ID is set to zero, the packet may not be part of a TCP flow and may be pushed to the IP layer. If the flow ID is not set to zero, the receiving OMMA layer may compare the sequence number with the next expected sequence number for that specific flow. If it is the next expected packet, the OMMA layer may be forwarded to the IP layer. If it is not the next expected packet, the receiving OMMA layer may hold the packet and start a timer. Upon expiry of the timer, the packet may be forwarded to the IP layer. If other packets are received while the timer has not expired, the OMMA layer may perform the same logic, forwarding it to the IP layer if it is the next expected packet. As new packets are received, the packets that are being held, as a result of not being the next expected packet, may be re-evaluated to see if they are now the next expected packet. If they are the next expected packet, the OMMA layer may forward the packet to the IP layer without waiting for the timer to expire.

[0179] The OMMA layer at the sender may use feedback from the MACs of each link to attempt to schedule the sending of the packets to maximize the likelihood that they are received in order, or as close as possible, to not trigger the congestion control mechanisms within TCP. While TCP may not require in order packets, it may do some reordering on its own and it may be

tolerant of some out of order packets. This may minimize the amount of data that is out-of order. The feedback parameters that may be used within the OMMA layer are described herein.

[0180] An example of the logic and queuing structures that may be used include, but are not limited to, the packets from the IP layer that may be merged into a single buffer, each MAC may have a very small buffer, and a timer may be used for each MAC queue. Packets from the IP layer may be merged into a single buffer. The OMMA layer may service the buffer one packet at a time and may make a decision as to which transport should be used, which, for example may including determining which transport provides the highest likelihood that the packet may be received in order. Each MAC may have a small buffer. The OMMA layer may place each packet into these buffers if the buffer is not full, for example, based on the decision criteria. A timer may be used for each MAC queue, for example, so if a packet does not make it out of the buffer in the required timer and it is a protocol that has retransmissions (*e.g.*, TCP), it may be dropped, for example, since the packet is part of a protocol which has retransmissions.

[0181] TCP may allow for packets to be received out of order. An attempt may be made to deliver the packets in as much of an ordered fashion as possible. Routing decisions may be made on a packet to attempt to minimize the disruption within the receiving TCP entity. For example, a transport decision for every x packets of every flow may be made, for example, instead of making a transport decision for every packet of every flow. Making the decision of whether to use the same transport or move the flow to another transport may be performed periodically instead of for every packet. This may minimize the amount of reordering and out-of-order packets that may occur within the receiving TCP entity. The value of x may be different for each type of IP flow. Feedback from the TCP entity and/or the MAC entity may be utilized, for example, to adjust the value of x dynamically.

[0182] FIG. 23 is a diagram illustrating an example of how an OMMA layer may route packets. FIG. 23 illustrates that the OMMA layer may decide to keep the TCP packets on one transport. The UDP packets may be transmitted over both transports. For example, the OMMA layer may utilize the 5-tuple of each packet and determine to keep or not keep the TCP IP flows on the same transport. For example, the OMMA layer may move them periodically.

[0183] The OMMA may maintain and reference a table that has information for each 5-tuple that the OMMA receives from the IP layer. FIG. 24 is a diagram illustrating an example of a table that may be maintained by an OMMA layer. The 5-tuple fields may be populated by the OMMA layer, for example, based on the IP packets it receives from the IP layer. If an IP packet arrives with a new 5-tuple, a new row may be added to the table. The current transport field may be filled in by the OMMA layer, for example, whenever it changes the transport that it plans to

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use for a specific 5-tuple. This may include selecting the transport once the first packet in a transport arrives for scheduling. The evaluation period may be a time of how often the OMMA layer may check to see if a TCP flow may be moved from one transport to another. Depending on the mode, this field may or may not be used. The OMMA layer may receive or determine the evaluation period from a policy. For example, if the evaluation period is 50 msecs, then the OMMA layer may revisit the routing decision every 50 msecs.

[0184] The split may be used by the OMMA layer to indicate how much of each IP flow may be routed over each transport. This may or may not be used depending on the mode. If the mode is set to split, then the OMMA layer may split the flow according to the percentages. For example, the OMMA layer may do this if the IP flow is TCP or UDP. For a TCP flow, aggregation may be performed, for example, 90% on one transport with the remaining 10% on another transport. For a UDP flow, aggregation may be performed, for example, according to some fixed percentages. These split percentages may come from a policy file.

[0185] The mode may be used to tell the OMMA layer how it may make scheduling decisions. For example, if the mode is set to split, then the scheduler of the OMMA layer may use the split percentages to make scheduling decisions. If the mode is not set to split, then the scheduler of the OMMA layer may do other logic. This logic may depend on the packet type. For TCP, it may use the current transport until the evaluation time has been reached, then re-evaluate which transport to use. Once this re-evaluation has been decided, the OMMA layer may use that decision until the next period has elapsed. For UDP, the OMMA layer may determine the best transport to use for every packet that it schedules. Evaluation period, split, and/or mode may be filled in by the OMMA layer, for example, utilizing one or more of the rules and/or policies described herein. The evaluation period may be for TCP flows. Split and/or mode may be for TCP ad/or UDP flows.

[0186] The logic to determine the best transport may be described herein. For example, it may be the transport with the most available capacity, or the lowest latency or the lowest jitter. For example, it may be a combination of the criteria described herein or it may be defined per 5-tuple. For example, it may be as a result of metrics received from the TCP entity and/or the MAC entities.

[0187] FIG. 25 is a diagram illustrating an example of the logic 2500 that may be used by an OMMA layer when there is a packet to be scheduled. A packet may be received by the OMMA layer at 2501. It may be determined at 2502 whether the packet is in a table (*e.g.*, the table of FIG. 24). If the packet is not then in table, then it may be determined that the packet is a packet from a new IP flow. If the packet is in the table, then it may be determined that the

packet is from an existing IP flow. At 2503, it may be determined whether the packet is a UDP packet. If the packet is a UDP packet, then it may be determined how to route the UDP packet at 2505. If the packet is not a UDP packet (*e.g.*, a TCP packet), then it may be determined how to route the packet at 2504. If the packet is from an existing IP flow, there may be a unique logic for UDP and/or TCP packets. Based on the packet type, UDP logic (*e.g.*, Figure 26) or the TCP logic (*e.g.*, Figure 27) may be used.

[0188] At 2506, if the packet is from a new IP flow, the best transport to route this packet may be determined by the OMMA layer and the packet may dispatched on that transport. The best transport may be the transport with the most capacity, the lowest latency, the least jitter, *etc.* After the routing or transport technique is determined, then the table may be updated with the packet at 2507. The packet may then be queued onto a separate transport.

[0189] FIG. 26 is a diagram illustrating an example of UDP logic that may be utilized by an OMMA layer. The UPD logic may look at the mode for the specific 5-tuple at 2601. If the mode is split, then the packet may be routed over the transport that best maintains the split percentages in the table. At 2602, if the mode is set to follow the split in the table for this packet, then the transport that best maintains the split may be determined. For example, if the split in the table is 50%-50%, then the OMMA layer may alternate between the transports when sending the packet. If the mode is not split, then the packet may routed over the best transport. For example, at 2603, since the packet is a UDP packet, the best transport may be determined for routing the packet. For example, the transport with the most capacity, the lowest latency, the least jitter, *etc.*

[0190] FIG. 27 is a diagram illustrating an example of TCP logic that may be utilized by an OMMA layer. The TCP logic may look at the mode for the specific 5-tuple at 2701. If the mode is split, then the packet may be routed over the transport that best maintains the split percentages in the table at 2702. Checks in this path may be utilized, for example, since there may be limits to how much aggregation may be done with TCP without causing a problem. If the limit is a 90%-10% split, then this logic may preclude an entry of a 50%-50% split between the transports. If the mode is not split, then the evaluation period may be consulted at 2703. If it is time to re-evaluate which transport is used for this specific IP flow, then a decision may be made, for example; do we leave the IP flow on the current transport or do we move it to the other transport. If it is not time to re-evaluate which transport is used for this specific IP flow at 2704, then the packet may be dispatched using the current transport. If there is time to re-evaluate which transport is used for the IP flow at 2705, then the best transport may be selected. For example, since this may be a TCP packet, the OMMA layer may re-evaluate (*e.g.*, periodically re-evaluate) which transport to use. After a determination is made by the OMMA layer, the

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OMMA layer may continue to utilize that transport until the next time to evaluate occurs. The best transport may be the transport with the most capacity, the lowest latency, the least jitter, *etc.*

[0191] Using multiple RATs simultaneously may provide the benefit of increased bandwidth for an application (*e.g.*, an IP flow) as well as increased reliability. As described herein, the OMMA layer may manage multiple RAT interfaces efficiently and enable aggregation of an IP flow across multiple RAT interfaces or segregation of an IP flow over specific RATs. As described herein, the OMMA layer may reside below the IP layer and above the RAT protocol stacks. The OMMA layer may include control plane and data plane processing capability.

[0192] The OMMA layer may receive metadata/link statistics feedback from each RAT. Within the OMMA layer, an OMMA scheduler may be responsible for traffic shaping, for example, by policy-based routing of IP packets across bands or feedback-based routing of packets across bands. The OMMA layer may be transparent in that it distributes and/or combines packets from different RATs and forwards the packets to the IP layer. The OMMA layer may be non-transparent, in that it adds additional headers at the transmitter, and/or reads and removes the headers at the receiver. The OMMA layer may utilize a packet distribution mode. As described herein, the packet distribution mode may be a diversity mode, a multiplexing mode, a hybrid mode, and a dynamic RAT selection mode.

[0193] Beacons, probe request/response and/or association request/response frames may be updated to include OMMA layer discovery parameters, for example, in WiFi based RATs. OMMA layer discovery parameters may include, but are not limited to, OMMA modes, OMMA schemes, OMMA packet distribution modes, *etc.*

[0194] Using multiple RATs simultaneously may provide increased bandwidth and/or increased reliability for an application. For example, a system comprising an OMMA layer may intelligently manage data traffic across multiple RATs for improved performance by dynamically scheduling data packets across RATs as a function of the link quality of each RAT. The OMMA layer may employ an architecture that handles control plane and data plane processing. The OMMA layer may comprise logical entities that may be separated into different physical entities in a network, for example, to enable many possible physical network implementations to achieve improved multi-RAT operation. The OMMA layer may evaluate (*e.g.*, periodically evaluate) RAT availability of a device (*e.g.*, a WTRU or NT). The OMMA layer may store information regarding RAT availability and/or may utilize information regarding RAT availability for RAT selection.

[0195] IP fragmentation may depend on the maximum transmission unit (MTU) size of the RAT. If a terminal supports multiple RATs, one or more of the RATs may have a different MTU size. An OMMA layer may support unequal MTU sizes of RATs, for example, by supporting fragmentation and reassembly of packets. For example, the OMMA layer may receive MTU information associated with one or more RATs, packet size information associated with one or more IP packets (*e.g.*, of an IP flow), and adjust a size of a MTU of a RAT according to the MTU information associated with the one or more RATs. For example, the OMMA layer may receive first MTU information associated with a first RAT, and receive second MTU information associated with a second RAT. The OMMA layer may receive packet size information associated with a first IP packet, and receive packet size information associated with a second IP packet. The OMMA layer may adjust at least one of a size of a MTU of the first IP packet and a size of a MTU of the second IP packet based on the first MTU information and the second MTU information. The OMMA layer may adjust the size such that the size of the MTU of the first packet is different from the size of the MTU of the second packet. The OMMA layer may adjust the size such that the size of the MTU of the first packet is the same as the size of the MTU of the second packet.

[0196] An OMMA layer may comprise a mechanism to readjust the assigned medium resources to a WTRU on each RAT, for example, based on global knowledge of resource assignment on other RATs. For example, the OMMA layer may utilize MAC resource reservation to achieve globally optimal resource allocation across RATs.

[0197] As described herein, a device (*e.g.*, a WTRU or NT) may include an OMMA layer that manages multiple RAT interfaces to enable opportunistic RAT selection and aggregation for sending data traffic over more than one RAT interface. The OMMA layer may reside below the IP layer and/or above the RAT protocol stacks. The OMMA layer may include control plane and/or data plane processing capability. The control plane may handle, for example, MAC resource reservation, RAT availability update management, and fragmentation control. The data plane may handle, for example, policy-based scheduling and feedback-based scheduling. The OMMA layer may define entities, for example, a policy database and a WTRU RAT capability database.

[0198] An OMMA layer (*e.g.*, subsystem or module) may reside between the RAT protocol stacks and the IP layer, for example, in the case of a multi-RAT network terminal. For example, interfaces disclosed herein may be standardized as a service access point (SAP) between the RAT protocol stacks and the OMMA layer.

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[0199] Part of or the entirety of the OMMA layer may reside as a logical entity on another device external to the multi-RAT network terminal, for example, such as but not limited to a common gateway (GW), which may comprise a wired network interface. Multiple single RAT network terminals may be distributed across a geographic area, for example, a large enterprise, and the OMMA layer (*e.g.*, partially or wholly) may reside on a common gateway (GW), which may have a wired network interface. The entirety of the OMMA layer may reside in the GW. A portion of the OMMA layer (*e.g.*, some functions of the OMMA layer) may reside in the GW, while the rest of the OMMA layer may reside within a network terminal. The physical interface between the GW and the network terminal may be standardized. For example, if the physical interface between the GW and the network terminal is wireless, then the signals may be standardized and/or detectable. For example, the OMMA controller, policy database, WTRU RAT capability database, DNS-APP, and UI-APP may reside on the GW, while the OMMA scheduler may reside on a network terminal.

[0200] As described herein, a node (*e.g.*, a NT or a WTRU) comprising an OMMA layer may aggregate bandwidth available on multiple radio access technologies (RATs). The node may establish a communication path via one or more RATs. For example, the node may establish a first communication path via a first RAT associated with the node, and establish a second communication path via a second RAT associated with the node. The node may receive feedback information associated with the one or more RATs. For example, the node may receive first feedback information associated with the first RAT, and receive second feedback information associated with the second RAT. The node may determine to send one or more IP packets of an IP flow across the one or more RATs, for example, as described herein (*e.g.*, using feedback information, one or more policies/rules, a distribution mode, *etc.*). For example, the node may determine a first IP packet to send via the first RAT according to the first and second feedback information. The node may also determine a second IP packet to send via the second RAT according to the first and second feedback information. The first and second IP packets may be part of an Internet Protocol (IP) flow addressed to a receiving node (*e.g.*, which may be a NT or a WTRU). The node may send one or more IP packets via the one or more RATs. For example, the node may send the first IP packet via the first RAT and send the second IP packet via the second RAT.

[0201] FIG. 28 is a functional block diagram illustrating an example implementation of an OMMA layer. As shown in FIG. 28, the OMMA layer 2800 may comprise an OMMA Controller 2810, an OMMA Scheduler 2820, a RAT Capability Database 2830 (*e.g.*, which may be referred to as a WTRU RAT Capability Database), and a Policy Database 2840.

[0202] The OMMA Controller may send control parameters to the OMMA Scheduler and/or the WTRU Capability Database. The control parameters may be used to make a decision on RAT selection for incoming IP packet flow. These parameters may be based on feedback from RATs and/or control information of incoming IP packets.

[0203] FIG. 29 is a functional block diagram that depicts an example implementation of an OMMA Controller. As shown in FIG. 29, the OMMA Controller 2900 may comprise a Multi-RAT Multi-Band Device Discovery module 2910 that may keep track of initial discovery and/or association phase results from each RAT, or example, through an interface A3 (*e.g.*, as shown in FIG. 28). After receiving the maximum RAT capability of other devices (*e.g.*, WTRU or NT) via a beacon request and/or probe response, the Multi-RAT Multi-Band Device Discovery module 2910 may calculate a list of matched RATs and may send this information to a RAT Protocol stack, for example, using the interface A3 (*e.g.*, as shown in FIG. 28). The Multi-RAT Multi-Band Device Discovery module 2910 may save the associated device's maximum RAT capabilities in the RAT Capability Database (*e.g.*, RAT capability database 2830), for example, through an interface A1 (*e.g.*, as shown in FIG. 28). The Multi-RAT Multi-Band Device Discovery module 2910 may send its own system parameters to RATs, which may be used in initial discovery and association process for advertisement, for example, through the interface A3 (*e.g.*, as shown in FIG. 28).

[0204] The OMMA Controller 2900 may comprise a Multi-RAT Multi-Band Security module 2920 that may store one or more security parameters (*e.g.*, GMKSA) that may be generated at different phases of security association between a WTRU and a NT, for example, to enable multi-RAT multi-band security.

[0205] The OMMA Controller 2900 may comprise a Feedback Device Classifier module 2930. A RAT (*e.g.*, each RAT) may provide feedback metrics (*e.g.*, a vector comprising a value of serving rate, jitter, packet delay, and packet loss rate on its MAC) to the OMMA Controller 2900 per device (*e.g.*, WTRU or NT) per access category supported at that RAT. This may be performed through interface A2 (*e.g.*, as shown in FIG. 28). The Feedback Device Classifier module 2930 may classify the metrics for each device address (*e.g.*, WTRU address or NT address), for example, so that the OMMA Controller 2900 may send feedback metrics to each device's OMMA layer (*e.g.*, since each device may have different RAT capability), for example, through interface A5a (*e.g.*, to a Feedback Based Scheduler (FBS) of OMMA Scheduler) and/or interface A5b (*e.g.*, to a Policy Based Scheduler (PBS) of OMMA Scheduler) (*e.g.*, as shown in FIG. 28).

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[0206] The OMMA Controller 2900 may comprise a Feedback QoS Classifier module 2940. The Feedback QoS Classifier module 2940 may classify the feedback metrics based on their access category ID, for example, so that it can send feedback per device per access category through interface A5a and/or A5b (*e.g.*, as shown in FIG. 28).

[0207] The OMMA Controller 2900 may comprise a RAT Update Management module 2950. RAT availability of a device (*e.g.*, WTRU) may change with time (*e.g.*, due to mobility, a device may have different RATs enabled at different times), so the RAT Update Management module 2950 may keep track of RAT capability/availability of associate devices. The RAT Update Management module 2950 may receive the knowledge of RAT availability by using interface A3 with the RAT Protocol stack (*e.g.*, as shown in FIG. 28). The RAT Update Management module 2950 may maintain the associated device's RAT availability list via a periodic update message from each WTRU, for example, at the NT side. It may use the Beacons received from a NT (*e.g.*, periodically) to maintain the NT's RAT availability list, for example, at the WTRU side. The RAT Update Management module 2950 may reflect changes of available RATs in a RAT Capability Database (*e.g.*, RAT capability database 2830), for example, on both sides, for example, through interface A1 (*e.g.*, as shown in FIG. 28).

[0208] The OMMA Controller 2900 may comprise a Packet Arrival Rate Estimation module 2960 that may be used to estimate the rate at which IP packets arrive at the OMMA layer from the IP layer. The arrival rate may be calculated as $x = 1/E[ti+1-ti]$ for all $i = 1, \ldots, n$, where ti may be the time instant at which packet Id "I" arrives at the OMMA layer, ti+1 may be the time instant at which packet Id "i+1" arrives at the OMMA layer, and E[.] may represent an expectation operation (*e.g.*, a moving average or an exponential average). (ti+1-ti) may represent the inter-arrival time between successive packets. This arrival rate "x" may be appended with one or more feedback metrics and/or sent to the FBS.

[0209] The OMMA Controller may comprise a MAC Resource Reservation module 2970 that may reserve required resources on one or more RATs. The MAC Resource Reservation module 2970 may reserve resources (*e.g.*, a fixed amount of bandwidth for a fixed amount of time) on one or more RATs, for example, based on the feedback metrics from the RATs and/or QoS requirements of incoming IP packets. The decision of requirement may be based on some predefined policies stored in a policy database. The reservation signaling between an OMMA Controller 2900 and a corresponding RAT may be performed through interface A3 (*e.g.*, as shown in FIG. 28). The OMMA Controller 2900 may access the Policy Database (*e.g.*, policy database 2840) through interface A10 (*e.g.*, as shown in FIG. 28).

[0210] The OMMA Controller 2900 may comprise a Fragmentation Controller module 2980 that may make decisions for enabling of fragmentation (*e.g.*, within the OMMA Scheduler) for an incoming IP packet. For an IP packet, the RAT selection decision may be sent from the OMMA Scheduler to this module (*e.g.*, within the OMMA Controller 2900), for example, through an interface A11 (*e.g.*, as shown in FIG. 28). The Fragmentation Controller 2980 module may receive the knowledge of MTU size of one or more RATs from a RAT Capability Database (*e.g.*, RAT Capability Database 2830), for example, using interface A1 (*e.g.*, as shown in FIG. 28). Based on the received RAT selection decision, MTU information for a RAT, and an incoming IP packet (*e.g.*, size), the Fragmentation Controller module 2980 may decide to enable or disable fragmentation (*e.g.*, within OMMA scheduler) for a RAT.

[0211] If the Fragmentation Controller module 2980 decides to fragment the IP packet on a RAT, it may enable a Packet Fragmentation module of the OMMA scheduler for that RAT given that fragmentation may be allowed by the IP layer for that IP packet. If the IP layer does not allow fragmentation for an IP packet, and the Fragmentation Controller module 2980 decides to fragment the IP packet on the RAT, it may send an ICMP unreachable error to the IP layer with the information of MTU size of that RAT (*e.g.*, in case of single RAT selection), or a minimum MTU size of one or more selected RATs (*e.g.*, in case of multiple RAT selection). If the Fragmentation Controller module 2980 determines that there is no requirement of fragmentation, then it may disable the Packet Fragmentation module of the OMMA scheduler of the corresponding RAT.

[0212] The OMMA Controller 2900 may comprise an OMMA Mode Management module 2990 that may manage the mode (*e.g.*, Transparent or Non-Transparent) of the OMMA Scheduler in which it has to operate. The OMMA Controller 2900 may make the mode decision and notify the OMMA Scheduler. The OMMA Mode Management module 2990 may receive the mode decision for a device (*e.g.*, WTRU) with the help of Policy Database (*e.g.*, policy database 2840), for example, using interface A10 (*e.g.*, as shown in FIG. 28). The OMMA Mode Management module 2990 may send this information to a corresponding device (*e.g.*, WTRU), for example, using interface A3 (*e.g.*, as shown in FIG. 28). This may be performed at the NT side. The OMMA Mode Management module 2990 may communicate with a RAT Capability Database (*e.g.*, RAT Capability Database 2830), for example, through interface A1 (*e.g.*, as shown in FIG. 28), for example, to query the RAT Availability list to select an available RAT for sending mode information. The OMMA Controller 2900 may inform the OMMA Scheduler about the mode decision, for example, using interface A9 (*e.g.*, as shown in FIG. 28). This may be performed on the WTRU side and/or the NT side.

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[0213] The OMMA Scheduler may determine the way packets are routed across one or more RATs (*e.g.*, as shown in FIG. 28). The OMMA scheduler may distribute the incoming IP packet flow to the selected RATs based on a chosen packet distribution algorithm. For example, the OMMA Scheduler may receive feedback for one or more RATs per access category from the Controller, for example, through interface A5a and A5b (*e.g.*, as shown in FIG. 28). Based on the QoS requirement (*e.g.*, received by the IP QoS Identifier), and/or feedback from the controller and one or more of the RATs (*e.g.*, capability), the OMMA scheduler may determine RAT(s) selection.

[0214] FIG. 30 is a functional block diagram illustrating one example of an OMMA Scheduler. For example, as shown in FIG. 30, an OMMA Scheduler 3000 may comprise a Policy Based Scheduler (PBS) module 3010. The PBS module 3010 may perform policy based routing, for example, where packets may be sent on different RATs using pre-defined rules (*e.g.*, operator policy, WTRU QoS class, *etc.*). The PBS module 3010 may utilize feedback metrics received from an OMMA Controller, for example, through interface A5b (*e.g.*, as shown in FIG. 28). As described herein, the rules may include, but are not limited to, one or more of device capability, an operator policy, a quality of service (QoS) class, an IP packet flow, device coordinates, a source domain, a source IP address, a destination domain, a destination IP address, a port number, a subscriber priority, a link quality, charging, security, the rules/policies described in Table 5, *etc.*

[0215] The OMMA Scheduler 3000 may comprise a Feedback Based Scheduler (FBS) module 3020. The FBS module 3020 may perform feedback based routing, for example, where packets may be sent on different RATs using feedback metrics (*e.g.*, RSSI, medium access delay, *etc.*), which may reflect the average state of the link between NT and WTRU on each RAT. These feedback metrics may be received from the OMMA Controller, for example, through interface A5a (*e.g.*, as shown in FIG. 28). As described herein, the feedback may include, but is not limited to, one or more of a medium access delay, jitter, a frame error rate, an average data rate, a received signal strength indication (RSSI) level, queuing latency per access category per RAT, end-to-end latency, a backoff time, a number of channels, channel bandwidth, a media access control (MAC) type, MAC aggregation support, an access category, a transmission opportunity (TXOP) duration, an estimated arrival rate of a packet, an average packet delay, packet loss rate (or frame error rate), queuing latency, number of MAC retransmissions, an average physical layer data rate, an average serving rate, an average serving latency, a serving delay variance, a second moment of average serving latency, vacation time, an average vacation

time, a second average of vacation time, a vacation time variance, QoS_ID, TCP parameters, such as sequence number, acknowledgement number, and window size, for example, *etc.*

[0216] Feedback metrics, such as, but not limited to medium access delay, frame rate error, data rate, queuing latency, end-to-end latency, TXOP duration, AC with medium access, backoff time, number of channels, MAC aggregation supported, MAC type, jitter, serving delay, serving delay variance, vacation time, vacation time variance, STA_Addr, QoS_ID, and number of MAC retransmissions may be provided to the OMMA layer from the MAC layer. Feedback metrics, such as, but not limited to, RSSI, number of channels, and channel bandwidth may be provided to the OMMA layer from the MAC layer.

[0217] Medium access delay may refer to the total packet delay in a queue plus a contention delay. The medium access delay may be the duration from the time when packet is inserted into the transmission queue at the MAC layer until the time when the frame is sent to the physical layer. Jitter may refer to the difference T_J between one way delay of successive packets at a sender and a receiver, for example, ignoring lost packets. T_J may be defined as the difference t_0 and t_1, where:

t_0 :'Inter-arrival time between successive packets at receiver'; and

t_1 : 'Inter-arrival time between successive packets at sender'.

[0218] Serving rate may be calculated as $1/T_i$, where T_i may be an average serving delay per packet at RAT_i. T_i may be defined as time duration from t_0 to t_1, where:

t_0 - time stamp MAC start perform CSMA/CA for that packet; and

t_1 - time stamp when ACK for that whole packet is received successfully at MAC layer of sender node.

[0219] Serving latency/delay may equal one divided by the serving rate (*e.g.*, 1/serving rate). The average packet delay may refer to the total delay experienced by an IP packet from the time t_a it enters the MAC queue until the time t_b when the ACK for the packet is received at the sender. The average packet delay may be the summation of queuing delay and serving delay at a MAC layer for an IP packet.

[0220] Vacation time may be the time duration for a NT to stop serving a particular queue in order to serve another queue (*e.g.*, a queue belonging to another WTRU, to send data of other Access Categories, *etc.*). The packet loss rate may be referred to as the frame error rate. The packet loss rate may be an average number of packets/frames in error in a unit time.

[0221] Queuing latency may be the total delay experienced by an IP packet from the time t_a it enters the MAC layer queue until the time t_0 when MAC layer may begin to perform CSMA/CA for that packet. The number of MAC retransmissions may be the average number of

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MAC retransmission attempts per packet. The RSSI level may be an average RSSI level of a signal from a WTRU, for example, as measured at a NT. The average physical layer data rate may be the average data rate per second for a NT-WTRU link.

[0222] Serving delay variance may be calculated by:

$$\delta^2 = \frac{\sum_{i=1}^{N} X^2}{N} - \left(\frac{\sum_{i=1}^{N} X}{N}\right)^2$$

where δ^2 may be the serving delay variance, X may be the serving delay, and N' may be the number of samples being used to calculate the serving delay variance.

[0223] Vacation time variance may be calculated by:

$$\delta^2 = \frac{\sum_{i=1}^{N} X^2}{N} - \left(\frac{\sum_{i=1}^{N} X}{N}\right)^2$$

where δ^2 may be the vacation time variance, X may be the vacation time, and N' may be the number of samples being used to calculate the vacation time variance.

[0224] STA_Addr may the WTRU address to associate feedback metrics with the appropriate NT-WTRU link. QoS_ID may be an access category identified (AC_BK, AC_VO, AC_BE, *etc.*) to associate feedback metrics with an appropriate access category.

[0225] The OMMA Scheduler 3000 may comprise a RAT Update Sender module 3030. The RAT Update Sender module 3030 may extract (*e.g.*, periodically extract) information regarding RAT availability from the RAT Capability Database (*e.g.*, RAT Capability Database 2830), for example, through interface A4 (*e.g.*, as shown in FIG. 28). The RAT update sender 3030 may send this information to the corresponding NT using over-the-air signaling.

[0226] The OMMA Scheduler 3000 may comprise a Device Capability Database Query module 3040. The Device capability database query module 3040 may communicate with the RAT Capability Database (*e.g.*, RAT Capability Database 2830) to query about the RAT capability/availability of a specific device (*e.g.*, WTRU). The RAT capabilities may be provided by the capability database in its response. This may be performed through interface A4 (*e.g.*, as shown in FIG. 28).

[0227] The OMMA Scheduler 3000 may comprise a Packet Fragmentation module 3050. The Packet Fragmentation module 3050 may be responsible for packet fragmentation of incoming IP packets from the IP layer at the OMMA sender (*e.g.*, for each RAT). The decision of fragmentation may be received from the Fragment Controller module of the OMMA Controller. Based on this decision, the packet fragmentation module 3050 may fragment the incoming packet or may not fragment the incoming packet. After this operation, the packet fragmentation module 3050 may send the packet to a lower layer.

[0228] The OMMA Scheduler 3000 may comprise an Rx Duplicate Packet Detection/Recovery module 3060. A sender may switch RATs, for example, in the case of a single RAT selection at any given time. When a RAT switch happens, the OMMA sender may duplicate packets to avoid out-of-order packet reception at the OMMA receiver. The Rx Duplicate Packet Detection/Recovery module 3060 may perform duplicate packet detection and removal, for example, at the OMMA receiver.

[0229] The OMMA Scheduler 3000 may comprise an Rx Packet Reassembly module 3070. The Rx Packet Reassembly module 3070 may be responsible for packet reassembly of fragmented packets at the OMMA receiver (*e.g.*, in case any fragmentation occurred at the OMMA sender) (*e.g.*, at each RAT). The Rx Packet Reassembly module 3070 may determine the OMMA header (*e.g.*, if it is operating in Non Transparent mode) to receive the knowledge of whether reassembly is required (*e.g.*, at each RAT). If there is no need of reassembly, the Rx packet reassembly module 3070 may send the packet to an upper module (*e.g.*, an Rx Duplicate Packet Detection/Recovery module 3060). If it is determined that reassembly is needed, the Rx Packet Reassembly module 3070 may reassemble incoming packets on the RAT before transmitting them to an upper module.

[0230] The OMMA Scheduler 3000 may comprise an Rx Reordering Buffer module 3080. A sender may switch RATs frequently, for example, in the case of a single RAT selection at any given time. When a RAT switch happens, for example, a switch from a high latency RAT to a low latency RAT, packets may be received out-of-order for a single IP stream. The Rx Reordering Buffer module 3080 may maintain the order of IP packets before sending them up to an IP layer.

[0231] The OMMA Scheduler 3000 may comprise an IP Packet Classifier module 3090. The OMMA layer may maintain a separate OMMA scheduler 3000 for each device (*e.g.*, WTRU), for example, to support multi-device (*e.g.*, multi-WTRU) association at another device (*e.g.*, NT). Since a device (*e.g.*, a WTRU) may have different RAT capabilities, selection of RATs for an IP packet may be different for each device, for example, based on policies such as, but not limited to QoS requirements of each IP flow. Through the IP Packet Classifier module 3090, the OMMA layer may read the header of the incoming IP packet and determine the destination (*e.g.*, WTRU) address. The OMMA layer may send the packet to the corresponding device's (*e.g.*, WTRU's) OMMA scheduler instance.

[0232] The OMMA Scheduler 3000 may comprise an IP Packet QoS Identifier module 3095 that may take an incoming IP packet and read the header information regarding the IP QoS class of the packet. The IP Packet QoS Identifier module 3095 may map the IP QoS class to one

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or more (*e.g.*, four) MAC access categories. This information may be used by the PBS module 3010 and/or FBS module 3020 to determine RAT selection for an IP packet.

[0233] Referring to FIG. 28, the OMMA layer may comprise a RAT capability database 2830 may store the RAT capability information of associated WTRUs at NTs and/or associated NTs at WTRUs. This database 2830 may comprise multiple types (*e.g.*, three types) of information relating to available RATs for an associated WTRU/NT. This information may include, but is not limited to, maximum capability of RAT (*e.g.*, per WTRU or per NT), available RATs at a given time (*e.g.*, per WTRU or per NT), and MTU for each RAT.

[0234] The RAT capability database 2830 may store the Maximum Capability of a device (*e.g.*, WTRU) after a Discovery and Association phase, representing the maximum RAT capability (*e.g.*, and not just those which may have better instantaneous channel quality) of a device (*e.g.*, WTRU). This information may be stored in the RAT capability database 2830 by the OMMA Controller, for example, through interface A1 (*e.g.*, as shown in FIG. 28).

[0235] The RAT capability database 2830 may store the Available RATs at a given time for a device (*e.g.*, WTRU). The maximum RAT capability (*e.g.*, a subset of maximum RAT capability) may be enabled at a given time, for example, based on the average link quality (*e.g.*, temporary availability/unavailability of RATs due to mobility). The RAT Capability Database 2830 may store this available RAT information for an associated device (*e.g.*, WTRU). The OMMA Controller may update (*e.g.*, continuously update) the available RAT capability of a device (*e.g.*, WTRU) in this database 2830, for example, based on feedback metrics from each RAT.

[0236] The RAT capability database 2830 may store the Maximum Transmission Unit (MTU) size for an available RAT. The Packet Fragmentation/Reassembly module of the OMMA scheduler may perform MTU discovery of a RAT, and may store the MTU size in the capability database 2830. For example, for a RAT "i," if the maximum capability is "1" and availability is "1," then the OMMA layer may determine that the OMMA sender may schedule packets on this RAT. If the maximum capability is "1" and availability is "0," or if the maximum capability is "0" and availability is "0," then the OMMA layer may determine that the OMMA sender may not schedule packets on this RAT. Table 1 is an example representation of RAT capability storage where "1" may indicate a RAT is available, and "0" may indicate a RAT may not be available. The type of RAT (*e.g.*, LTE, 802.11n, HSPA, *etc.*) may be indicated by a predefined RAT ID.

Table 4

WTRU Address	RAT 1		RAT 2				RAT n	
	Max Capability	Availability	Max Capability	Availability			Max Capability	Availability
	MTU_1		MTU_2				MTU_n	
WTRU 1	1	1	1	0			1	1
WTRU 2	0	0	1	1			0	0
WTRU "k"	1	1	1	1			1	1

[0237] Referring to FIG. 28, the OMMA layer may comprise a Policy Database 2840 that may comprise one or more predefined policies/rules that may be designed for packet distribution on one or more RATs. The policies may be predefined by the administrator or operator. The policies may or may not be overwritten with new policies. As described herein, the policies/rules may include, but are not limited to, one or more of device capability, an operator policy, a quality of service (QoS) class, an IP packet flow, device coordinates, a source domain, a source IP address, a destination domain, a destination IP address, a port number, a subscriber priority, a link quality, charging, and security.

[0238] The Policy Database 2840 may comprise a list of local policies or rules. Table 2 provides examples of local policies or rules that may be stored in the Policy Database 2840.

Table 5

Type	Discriminators/Criteria/Events	Action
QoS	Voice traffic	Select RAT(s) with Jitter<50ms and packet latency < 5ms
	Video traffic	Select RAT(s) with Packet loss rate<5% and packet latency < 5ms
IP Flow	TCP traffic	Select RATs such that difference in serving latency is less than 1 ms
	UDP traffic	Select RATs such that difference in serving latency is less than 1 ms
Device co-ordinates	Location of device (*e.g.*: TVWS channels are available)	Look up TVWS database and enable TVWS based RAT
	Time of Day	Assign spectral bands(and corresponding RATs) available at that time
Operator's Policies	Single ISM Band Only	All traffic load will be schedule to send out on ISM band
	Single TVWS Band Only	All traffic load will be schedule to send out on TVWS band

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	Equal split between RATs			Half of traffic load will be scheduled on TVWS band. Remaining half will be scheduled on ISM band
	Pre-defined split between RATs			Traffic load will be split into two RATs to send out with a pre-defined ratio
	Load Balancing (No metric feedback)			Traffic split proportional to the Maximum Data Rate at PHY layer
Source Domain	Domain Name	IP Address	Token	
	Youtube.com	192.139.27.3	0	Select two or more RATs
	Netflix.com	178.392.83.6	1	
	twitter.com	195.287.23.8	1	Select one RAT
	google.com	158.275.74.6	0	
Source IP Address	173.23.45.0-173.23.45.255			Select two or more RATs
	154.65.66.66			
	65.27.1.55-65.27.2.0			Select one RAT
	8.8.8.8			
Destination Domain	Domain Name	IP Address	Token	
	Youtube.com	192.139.27.3	0	Select two or more RATs
	Netflix.com	178.392.83.6	1	
	twitter.com	195.287.23.8	1	Select one RAT
	google.com	158.275.74.6	0	
Destination IP Address	173.23.45.0-173.23.45.255			Select one RAT
	154.65.66.66			
	65.27.1.55-65.27.2.0			Select two or more RATs
	8.8.8.8			
Port Number	20 or 21(FTP traffic)			Select one RAT
	All other ports			Select one or more RATs
Subscriber Priority	Low			Select one RAT
	Medium			Select two RATs
	High			Select three RATs
Link Quality	Jitter>50ms			Do not assign RAT to Voice applications
	Packet loss rate>5%			Do not assign RAT to Video applications
	Packet latency>5 ms			Do not assign RAT to Voice or Video applications
	Throughput<1Mbps			Force Aggregation of Multiple RATs
Charging	Per unit time			Select RAT with the minimum charge per unit time
	Per data size(kB)			Select RAT with the minimum charge per data size (kB)
	No Charging			Select any RAT(s)
Security	VPN traffic			Select one RAT only; Disable multi-RAT aggregation
	VLAN			Select RATs on the same VLAN for aggregation

[0239] The Policy Based Scheduler module of the OMMA Scheduler may use one or more of the policies within the policy database 2840 to decide how to route packets. The policies within the policy database 2840 may comprise two sets of entries, discriminators/events and actions/results. There may be a one-to-one mapping between the discriminators/events and actions/results.

[0240] The discriminator/event may be evaluated at the start of an IP Flow, for example, periodically, continually, or based on an event (*e.g.*, a link going down or becoming available). If a discriminator/event is true, the result may be enforced. The discriminator/event may be for a specific IP Flow, a specific user, a specific transport, *etc.* A discriminator/event may be any combination of the above listed discriminators/events. A default discriminator/event may apply when none of the other discriminators/events are triggered or met.

[0241] The actions/results may be performed for a specific IP Flow, a specific user's IP Flows, or a specific transport's IP Flows. The actions/results proposed may be a RAT selector value. The value may be a number in a range (*e.g.*, [-x, x]). The value zero may indicate that there is no preference, for example, placing an IP Flow on either transport may be acceptable. The extremes (*e.g.*, -x and x) of the range may indicate whether an IP Flow should be placed on a specific RAT or if an IP Flow should not be placed on a specific RAT.

[0242] RAT availability update management may be described herein. The OMMA module architecture may be used to address discovery and availability detection of RATs. The members of a WTRU-NT pair may associate with each other by signaling their maximum matched RAT Capability at a given time. The RAT availability list for the WTRU-NT pair may change with time depending on several factors (*e.g.*, mobility, link quality fluctuation, *etc.*). Dynamic management of RAT availability may be implemented for a WTRU-NT pair, for example, in which a NT knows the RAT availability for an associated WTRU and a WTRU knows the RAT availability for the associated NT.

[0243] FIG. 31 illustrates an example call flow illustrating signaling corresponding to an example of a RAT availability update procedure described herein. A NT 3100 may send one or more beacons on its RATs (*e.g.*, periodically). A WTRU 3150 may receive knowledge of RAT availability for an associated NT through one or more beacons. A RAT that receives a beacon may inform/update the OMMA Controller 3160 (*e.g.*, RAT Update Management module) regarding RAT availability, for example, via a signal RAT_Capablities_A3 on interface A3 (*e.g.*, as shown in FIG. 28). The OMMA Controller 3160 (*e.g.*, RAT Update Management module)

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may update information of RAT availability in the RAT Capability Database 3170, for example, via a STA_RAT_Capability_Update_A1 signal on interface A1 (*e.g.*, as shown in FIG. 28).

[0244] At the WTRU side, the OMMA Scheduler 3180 (*e.g.*, RAT Update Sender) may query (*e.g.*, periodically query) the RAT Availability Database 3170 for a RAT availability list of an associated NT, for example, via a STA_RAT_Capability_Query_A4 signal on interface A4 (*e.g.*, as shown in FIG. 28). After receiving a response (*e.g.*, STA_RAT_Capability_Response_A4) for the above request, the OMMA scheduler 3180 may generate a STA_RAT_Availability message, for example, with one or more of the following parameters, to be sent using over-the-air signaling:

- STA_Addr : Self Address
- AP_Addr : Address of a NT (*e.g.,* which it needs to send a message)
- RAT_Ids : List of Ids of RATs (*e.g.,* which are available) (*e.g.*, [RAT_1, RAT_2 …..])

[0245] The OMMA Scheduler 3180 (*e.g.*, RAT Update Sender) at the WTRU 3150 may transmit RAT availability information to the NT 3100 using one of the operational RATs at that time. At the NT 3100, the RAT that receives the STA_RAT_Availability message may signal the OMMA Controller 3110 (*e.g.*, RAT Update Management module), for example, via a RAT_Capablities_A3 on interface A3 (*e.g.*, as shown in FIG. 28). The OMMA Controller 3110 (*e.g.*, RAT Update Management module) may update information of RAT Availability in the RAT Capability Database 3120 for that WTRU, for example, via a STA_RAT_Capability_Update_A1 signal on interface A1 (*e.g.*, as shown in FIG. 28). The RAT Availability information of a WTRU-NT pair may be refreshed (*e.g.*, periodically refreshed).

[0246] Multi-RAT fragmentation control at the OMMA layer may be described herein. The OMMA layer may be used for multi-RAT fragmentation control. For example, a WTRU may be associated with a NT. A single IP flow may be served by the NT-WTRU link. One or more fields (*e.g.*, *STA_Addr* and *IP_QoS_Type* fields) of the signals may be fixed. The NT-WTRU link may be configured to operate using one (*e.g.*, only one) of its RATs at any given time. For example, even if a NT and a WTRU are capable of multiple RATs, one (*e.g.*, only one) of the RATs common to both NT and WTRU may be selected.

[0247] The OMMA layer at the sender, for example, at a NT when data traffic flows in the downlink direction from the NT to a WTRU, or, at a WTRU when data traffic flows in the uplink direction from the WTRU to a NT, may be described herein. The OMMA layer may receive packets from the IP layer and route the IP stream on to a selected RAT, for example, as determined by the PBS module and/or the FBS module.

[0248] FIG. 32 is a system diagram illustrating data flow in an example scenario of an OMMA sender in which both PBS and FBS are enabled at a NT for a single RAT selection for a single WTRU single IP flow. FIG. 33 illustrates an example call flow for this scenario. The Policy-Based Scheduler (PBS) module 3210 may determine a RAT selection based on one or more of a number of criteria. The PBS module 3210 may consider, for example, the RAT capability provided by the RAT Capability Database 3215, for example, using the interface A4 (*e.g.*, as shown in FIG. 32). The OMMA Controller 3220 may update the RAT Capability Database 3215 (*e.g.*, continuously) when there is a change in available RATs for a WTRU. The OMMA Scheduler 3225 may query (*e.g.* periodically query) the RAT Capability Database 3215 to check whether the RATs corresponding to the maximum capability of the WTRU are still available.

[0249] The PBS 3210 may consider feedback provided from the OMMA Controller 3220 for the IP flow's access category, for example, using the interface A5b (*e.g.*, as shown in FIG. 32). In this case of single RAT selection, certain parameters in signal *RAT_Metrics_PBS_A5b* (*e.g.*, on A5b interface) may be modified. The RAT_Id may be modified as the RAT ID of the enabled RAT. Metrics may comprise a number of parameters for the RAT with the Id given in the RAT_Id parameter. These parameters may include, but are not limited to, the average packet delay *Avg_Pkt_Delay*, a *Jitter* parameter, and a packet loss rate *Pkt_Loss_Rate*. The choice of RAT may be based on maximum bandwidth available, for example, at a cold start. The PBS module 3210 may make a priority list of RATs based on the bandwidth available for each RAT. For example, if there are policies defined for these conditions, the PBS module may choose a one or more RAT capabilities based on the defined policy or policies (*e.g.*, one or more of the policies/rules described herein). The PBS module 3210 may consider predefined policies from the policy database 3235, for example, using the interface A6 (*e.g.*, as shown in FIG. 32). After the PBS module 3210 makes the decision on RAT selection, the decision may be sent to the Feedback based scheduler (FBS) module 3230, for example, through interface A7 (*e.g.*, as shown in FIG. 32). A *RAT_Selection_List* parameter in the *RAT_Selection_Decision_A7* signal on the interface A7 may comprise a single selected RAT or list of RATs based on the decision taken by the PBS module 3210. If there are no predefined policies in the Policy Database 3235, the PBS module 3210 may make the decision based on the feedback metrics from the OMMA Controller 3220.

[0250] An incoming IP packet may be delivered directly to the FBS module 3230, for example, after the PBS module 3210 makes the decision as to RAT selection. If the PBS module 3210 provides a single selected RAT to the FBS module 3230, the FBS module 3230 may select

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the same RAT and route the IP packets on the Packet Fragmentation module of it. If the PBS module 3210 provides multiple RATs, the FBS module 3230 may select a RAT (*e.g.*, the best RAT), for example, based on the feedback metrics given by the OMMA Controller 3220, for example, through interface A5a (*e.g.*, as shown in FIG. 32). In this case of single RAT selection, certain parameters in the *RAT_Metrics_FBS_A5a* signal of A5a interface may be modified. For example, a parameter *RAT_Id* may be modified as the RAT ID of the enabled RAT. Metrics may comprise one or more parameters for the RAT with the ID given in the RAT_Id parameter. These parameters may include, but are not limited to, a packet arrival rate *Arrival_Rate*, a serving rate *Serving_Rate*, and an average packet delay *Avg_Pkt_Delay*. The choice of RAT may be based on the best RAT in the priority list provided by the PBS module 3210, for example, at a cold start. For example, as shown in FIG. 32, RAT 3240 may be currently configured to have packets scheduled over it (*e.g.*, send or receive), while RAT 3245 may be configured to have packets scheduled over it at a later time (*e.g.*, according to the selection procedures described herein). Therefore, all packets may be scheduled over a single RAT (*e.g*, RAT 3240) at a given time.

[0251] After receiving the final decision on RAT selection, the FBS module 3230 may route the packets on the selected RAT's Packet Fragmentation module. The FBS module 3230 may transmit the selected RAT decision to the Fragmentation Controller module of the OMMA Controller 3220 for example, through interface A11 (*e.g.*, as shown in FIG. 32). A parameter *RAT_Id_List* in *Frag_Decision_Request_A11* on interface A11 may be modified to comprise one element that is a RAT Id of the selected RAT.

[0252] The Fragmentation Controller module may receive the decision of fragmentation, for example, based on the request made through interface A11. If the fragmentation controller does not have MTU information of the selected RAT, it may communicate with the RAT Capability Database 3215 to receive MTU information, for example, using interface A1 (*e.g.*, as shown in FIG. 32). A parameter *RAT_Id_List* in a signal *STA_RAT_Capability_Query_A1* signal on A1 interface may be modified to comprise an element that is a RAT Id of the selected RAT.

[0253] The RAT Capability Database 3215 may transmit the response of the above request, for example, via interface A1 (*e.g.*, as shown in FIG. 32). A parameter *RAT_Id_List* in a signal *STA_RAT_capability_Response_A1* on A1 interface may be modified to comprise an element that is RAT Id of the selected RAT. A parameter *RAT_Info* may be modified to comprise an array of 3-tuples (*e.g.*, *MTU, Max_RAT_Capability, RAT_Availability*) for the *RAT_Id* of the selected RAT (*e.g.*, as specified in *RAT_Id_List*).

[0254] On the selected RAT, the Packet Fragmentation module may receive the decision of fragmenting or not fragmenting the incoming packet from the FBS module 3230, for example, based on the fragmentation decision received from the Fragmentation Controller module through interface A12. A parameter *RAT_Id_List* in a signal *Fragmentation_Decision_A12* on interface A12 may be modified to comprise the RAT Id of the selected RAT. A parameter *Frag_Decision_List* may be modified to comprise a value that represents the decision for fragmentation for the selected RAT, for example, "0" if fragmentation is off and '1" if fragmentation is on. The FBS module 3230 may transmit the fragments or packets without fragments to a lower layer.

[0255] A RAT switch may occur when the selected RAT is not able to fulfill the requirement of a given IP flow QoS Class. If the PBS module 3210 detects this situation, the PBS module 3210 may query the RAT Capability Database 3215 for RAT availability information, for example, through a *STA_RAT_Capability_Query_A4* signal on interface A4 (*e.g.*, as shown in FIG. 32). After determining the RATs that are available for the WTRU (*e.g.*, through the *STA_RAT_Capability_Response_A4* signal on interface A4), the PBS module 3210 may select (*e.g.*, randomly select) a RAT other than the current selected RAT from the RAT availability list. When a RAT switch occurs, the PBS module 3210 may signal the FBS module 3230 to duplicate one or more packets across the RATs to avoid out-of-order packet reception at the OMMA receiver. The RAT with the best feedback metrics, for example, such as but not limited to average packet delay or packet error rate, may be selected.

[0256] FIG. 34 is a functional block diagram illustrating an example of a transparent OMMA Receiver for a single RAT enabled, single WTRU, single IP flow. The OMMA layer 3400 at the receiver may be implemented at a NT when data traffic flows in the uplink direction from a WTRU to the NT, or, at a WTRU when data traffic flows in the downlink direction from a NT to the WTRU. The OMMA Controller 3410 may inform the OMMA Scheduler 3420 about the receiver mode (*e.g.*, Transparent or Non-Transparent) in which it operates. In transparent mode, the OMMA scheduler 3420 may receive packets from a RAT and pass the packets to the IP layer 3430, for example, without any additional processing (*e.g.*, as shown in FIG. 34).

[0257] Though a single RAT may be used at any given time, the sender may switch RATs (*e.g.*, frequently). When a RAT switch happens, for example a switch from a high latency RAT to a low latency RAT, packets may be received out-of-order for a single IP stream. For example as shown in FIG. 34, RAT 3440 may be currently configured to send/receive IP packets from the OMMA layer, although RAT 3445 may be configured to send/receive IP packets from the OMMA layer at a later time. A Reordering Buffer 3450 may maintain the order of IP

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packets before sending them to the IP layer 3430. If IP packets are duplicated across both RATs 3440, 3445 when a RAT switch happens, a duplicate packet detection module 3460 may detect and remove the duplicate IP packet, for example, at the OMMA receiver.

[0258] In case of fragmentation at the OMMA sender, reassembly may be done on the selected RAT at the OMMA receiver, for example, as shown in FIG. 35 (*e.g.*, which may be similar to that described with reference to FIG. 34). The reassembly decision may be taken based on a specific field in the OMMA header (*e.g.*, added for enabling fragmentation at OMMA sender).

[0259] MAC resource reservation at the OMMA layer may be described herein. FIG. 36 is a diagram that illustrates an example call flow for allocating wireless resources for medium access by a NT and a WTRU using the RAT. The MAC on a RAT may allocate wireless resources (*e.g.*, bandwidth and time duration) for medium access by the NT and WTRU utilizing the RAT. Since the OMMA layer may be part of a multi-RAT system with independent MACs (*e.g.*, one MAC for each RAT), a MAC may be unaware of the resource allocation to the NT and WTRU by other MACs. For example, multi-RAT resource allocation may not be globally optimal. Since the OMMA layer may be the common entity which is aware of the link quality metrics on each RAT for a device and QoS class (*e.g.*, every WTRU and every QoS class), a globally optimal resource allocation may be performed at the OMMA layer, and the optimal resource allocation may be signaled to the MAC on each RAT.

[0260] For example, the OMMA layer may determine a time duration and a bandwidth requirement for an IP flow. The OMMA layer may request resources on a first RAT and on a second RAT based on the time duration and the bandwidth requirement for the first IP packet and the second IP packet of the IP flow. The resources are characterized by the time duration and the bandwidth requirement. The OMMA layer may receive a quality of service (QoS) of the first IP packet and a QoS of the second IP packet. The resources on the first RAT and on the second RAT may be requested based on at least one of the feedback information relating to the first RAT, the feedback information relating to the second RAT, the QoS of the first IP packet, and the QoS of the second IP packet. The resources may be requested on the first RAT and on the second RAT using one or more of an A1 interface and an A2 interface. Although described with reference to two IP packets and two RATs, MAC resource reservation may be performed by the OMMA layer for any number of IP packets of an IP flow and for any number of different RATs.

[0261] Inter-module interfaces may be described herein. As described herein, the OMMA Controller may utilize one or more interfaces to communicate with one or more RATs,

the Feedback Based Scheduler and the Policy Based Scheduler within the OMMA Scheduler, the Policy Database, and/or the RAT Capability Database.

[0262] FIG. 37 is a diagram illustrating examples of signals that may be communicated and used between the OMMA controller and the RAT capability database. For example, the OMMA Controller 3700 may communicate with the RAT Capability Database 3710, for example, using interface A1. Through this interface the OMMA controller 3700 may query or update the database with the RAT capability of an associated device (*e.g.*, WTRU).

[0263] The interface between the OMMA Controller 3700 and the RAT Capability Database 3710 may communicate a signal *STA RAT Capability Update_A1* that may be used at both the OMMA Sender and Receiver. Using this signal, the OMMA Controller 3700 (*e.g.*, Multi-RAT Multi-Band Device Discovery or RAT Update Management module) may store the maximum RAT capability of a WTRU or NT (*e.g.*, each WTRU) that it obtains after initial discovery and association phase into RAT Capability Database 3710. The OMMA controller 3700 may update the availability/unavailability of RATs that it triggers due to mobility of a WTRU or fluctuation in link quality due to other environmental effects. The OMMA controller 3700 may determine the availability or unavailability of a RAT from feedback metrics of the RATs, for example, through interface A3.

[0264] The signal *STA RAT Capability Update_A1* may be aperiodic. The signal *STA RAT Capability Update_A1* may be used when a new WTRU is associated or when a change in the availability of a RAT occurs for an associated WTRU. The signal *STA RAT Capability Update_A1* may include a number of parameters, for example, an address *STA_Addr* of the WTRU, a list *RAT_Id_List* of RAT Id for the WTRU, and a parameter *Reason_for_Update* that comprises a value representing a reason for updating a RAT capability. For example, the *Reason_for_Update* parameter may store the value 0 for a new WTRU association or the value 1 for a WTRU RAT availability change.

[0265] The signal *STA RAT Capability Update_A1* may include a parameter *RAT_Info* that comprises an array. If the parameter *Reason_for_Update* stores a value of 0, the array may be an array of pairs (*e.g.*, *MTU, Max_RAT_Capability*) comprising as many triplets as there are RAT Ids in the *RAT_Id_List*. The default setting of *RAT*_availability on the RAT performing association may be set to "1," while it may be set to "0" for other RATs (*e.g.*, (*MTU1, Max_RAT1_Capability*),...,(*MTUn, Max_RATn_Capabilityi*)). If the parameter *Reason_for_Update* stores a value of 1, the array may be an array of *RAT_Availability* comprising many elements as there are RAT Ids in the *RAT_Id_List* (*e.g.*, *RA T1_Availability,...,RATn_Availability*).

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[0266] The interface between the OMMA Controller 3700 and the RAT Capability Database 3710 may communicate a signal *STA RAT Capability Query_A1* that may be used at the OMMA sender. It may be used by the OMMA Controller 3700 (*e.g.*, OMMA Mode Management or Fragmentation Controller module) to request the RAT Capability database 3710 for specific information regarding WTRU capability, for example, maximum RAT capability, available RATs, MTU size, *etc.*

[0267] The signal *STA RAT Capability Query_A1* may be aperiodic. The signal *STA RAT Capability Query_A1* may be used when the OMMA controller 3700 (*e.g.*, OMMA Mode Management or Fragmentation Controller module) needs information regarding WTRU's RAT capability. It may include a parameter *STA_Addr* that comprises the address of the WTRU for which parameters are requested and/or a parameter *RAT_Id_List* that comprises a list of RAT Ids for which parameters are requested.

[0268] The interface between the OMMA Controller 3700 and the RAT Capability Database 3710 may communicate a signal *STA RAT Capability Response_A1* that may be used at the OMMA sender. The RAT Capability database 3710 may respond to the signal *STA_RAT_Capability_Query_A1* by the OMMA Controller 3700 (*e.g.*, OMMA Mode Management or Fragmentation Controller module) using this signal. The signal *STA_RAT_Capability_Query_A1* may comprise specific information regarding WTRU capability, for example, maximum RAT capability, available RATs, MTU size, *etc.*

[0269] The signal *STA RAT Capability Response_A1* may be aperiodic. The signal *STA RAT Capability Response_A1* may be used in response to the *STA_RAT_Capability_Query_A1* signal. The signal may comprise a number of parameters, for example, the parameters described herein. These parameters may include, for example, an address *STA_Addr* of the WTRU for which parameters are requested, a list *RAT_Id_List* of RAT Ids for which parameters are requested, and an array *RAT_Info* of 3-tuples (*e.g.*, *MTU, Max_RAT_Capability, RAT_Availabilityi*) comprising as many 3-tuples as there are RAT Ids in the *RAT_Id_List* (*e.g.*, (*MTU1, Max_RAT1_Capability, RAT1_Availability*),..., (*MTUn, Max_RATn_Capability, RATn_Availability*)).

[0270] FIG. 38 illustrates an example of the interface between the OMMA Controller and the Policy Database. The OMMA Controller 3800 may communicate with the Policy Database 3810 using interface A10. Through the interface A10, the OMMA controller 3800 may query to access the predefined policies in the Policy Database 3810 (*e.g.*, those policies/rules described herein). The interface between the OMMA Controller 3800 and the Policy Database 3810 may communicate a signal *Policy_Query_A10* that may be used at the OMMA sender. The signal

may be used by the OMMA Controller 3800 (*e.g.*, MAC Resource Reservation or OMMA Mode Management module) to request the Policy database for specific information regarding policies specific to any WTRU or specific to any IP QoS traffic.

[0271] The signal *Policy_Query_A10* may be aperiodic. The signal *Policy_Query_A10* may be used when the OMMA controller 3800 (*e.g.*, MAC Resource Reservation or OMMA Mode Management module) needs information regarding Policy information regarding a WTRU or IP QoS traffic. The signal *Policy_Query_A10* may include a number of parameters, for example, an address *STA_ADDR* of the WTRU for which parameters are requested. A parameter *IP_QoS_Type* may store the QoS class of the IP packet for which parameters are requested. A parameter *Mode_Request* may store a value that indicates whether the mode request is off or on. For example, the parameter *Mode_Request* may store a value of 0 if the mode request is off and a value of 1 if the mode request is on.

[0272] The interface between the OMMA Controller 3800 and the Policy Database 3810 may communicate a signal *Policy_Response_A10* that may be used at the OMMA sender. The Policy database 3810 may respond to the *Policy_Query_A10* by OMMA Controller (*e.g.*, MAC Resource Reservation or OMMA Mode Management module) using this signal. The signal *Policy_Response_A10* may comprise information regarding policies to be applied when serving particular WTRUs and IP QoS traffic.

[0273] The signal *Policy_Response_A10* may be aperiodic. The signal *Policy_Response_A10* be generated as a response to *Policy_Query_A10*. The signal may include a number of parameters, for example, an address *STA_ADDR* of the WTRU for which parameters are requested. A parameter *IP_QoS_Type* may store the QoS class of the IP packet for which parameters are requested. A parameter *Policy* may store a policy that is defined in the policy database 3810 for a given *IP_QoS_Type* of a given *STA_Addr*. If there is no such policy, the parameter *Policy* may return a NULL value. A parameter *Mode* may return a mode defined in the policy database 3810 for a given *IP_QoS_type* for a given *STA_Addr*, for example, if the *Mode Request* is ON in *Policy_Query_A10*.

[0274] The OMMA Controller may communicate with the OMMA Scheduler, for example, using interfaces A5a, A5b, A9, A11, and A12 (*e.g.*, as shown in FIG. 39). FIG. 39 illustrates an example interface between an OMMA Controller and an OMMA Scheduler. The OMMA controller 3900 may communicate with the FBS module of the OMMA scheduler 3910 using interface A5a to signal feedback metrics. The OMMA controller 3900 may communicate with the FBS module of the OMMA scheduler 3910 using interface A11 to receive the RAT selection decision. The OMMA controller 3900 may communicate with the PBS module of the

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OMMA scheduler 3910 using interface A5b to signal the feedback metrics. The OMMA controller 3900 may communicate with the Packet Fragmentation module of the OMMA scheduler 3910 using interface A12 to signal the fragmentation enable/disable decision. Using interface A12, the OMMA Scheduler 3910 may signal the OMMA controller 3900 regarding the mode (*e.g.*, Transparent/Non-Transparent) in which it operates.

[0275] The interface between the OMMA Controller 3900 and the OMMA Scheduler 3910 may be utilized to communicate a signal *RAT_Metrics_PBS_A5b* that may be used at the OMMA sender. The OMMA Controller 3900 (*e.g.*, Feedback WTRU and QoS Classifier module) may signal the feedback metrics of a RAT to the PBS module of the OMMA scheduler 3910. The signal *RAT_Metrics_PBS_A5b* may be aperiodic. The OMMA controller 3900 (*e.g.*, Feedback WTRU and QoS Classifier module) may signal the feedback metrics based on a predefined period at which it gets feedback from the RATs.

[0276] The signal *RAT_Metrics_PBS_A5b* may include a number of parameters, for example, the parameters described herein. A parameter *RAT_Id* may comprise RAT IDs for which parameters apply. A parameter *STA_Addr* may comprise an address of the WTRU for which parameters apply. A parameter *IP_QoS_Type* may store QoS Classes for which parameters apply. Metrics may comprise a number of parameters for the RAT with the Id given in the RAT_Id parameter. These parameters may include, but are not limited to the average packet delay *Avg_Pkt_Delay*, a *Jitter* parameter, and a packet loss rate *Pkt_Loss_Rate*. These parameters may be signalled as a matrix, for example, as shown in FIG. 40.

[0277] The interface between the OMMA Controller 3900 and the OMMA Scheduler 3910 may communicate a signal *RAT_Metrics_FBS_A5a* that is used at the OMMA sender. The OMMA Controller 3900 (*e.g.*, Feedback WTRU and QoS Classifier module) may signal the feedback metrics of a RAT to the FBS module of the OMMA scheduler 3910. The signal *RAT_Metrics_FBS_A5a* may be aperiodic. The OMMA controller 3900 (*e.g.*, Feedback WTRU and QoS Classifier module) may signal the feedback metrics based on a predefined period at which it gets feedback from the RATs.

[0278] The signal *RAT_Metrics_FBS_A5a* may include a number of parameters, for example, the parameters described herein. A parameter *RAT_Id* may comprise RAT IDs for which parameters apply. A parameter *STA_Addr* may comprise an address of the WTRU for which parameters apply. A parameter *IP_QoS_Type* may store QoS Classes for which parameters apply. Metrics may comprise one or more parameters for the RAT with the Id given in the RAT_Id parameter. These parameters may include, but are not limited to, the arrival rate

Arrival_Rate, a serving rate *Serving_Rate*, and an average packet delay *Avg_Pkt_Delay*. These parameters may be signalled as a matrix, for example, as shown in FIG. 41.

[0279] The interface between the OMMA Controller 3900 and the OMMA Scheduler 3910 may communicate a signal *OMMA_Mode_Decision_A9* that is used at the OMMA sender and/or receiver. The OMMA Controller 3900 (*e.g.*, OMMA Mode Management module) may signal the OMMA Scheduler 3910 about the mode in which it operates.

[0280] The signal *OMMA_Mode_Decision_A9* may be aperiodic. The signal *OMMA_Mode_Decision_A9* may be used when a mode change is signaled by a NT for a WTRU. The signal *OMMA_Mode_Decision_A9* may include a number of parameters, for example, the parameters described herein. A parameter *STA_Addr* may comprise an address of the WTRU for which parameters apply. A parameter *IP_QoS_Type* may store QoS Classes for which parameters apply. A parameter *OMMA_Processing_Mode* may have a value of 0 if the OMMA processing mode is transparent and a value of 1 if the OMMA processing mode is non-transparent. A parameter *OMMA_Scheduling_Scheme* may have a value of 0 if the scheduling scheme is policy-based and a value of 1 if the scheduling scheme is feedback-based. A parameter *OMMA_Pkt_Dst_Mode* may have a value of 0 in a diversity mode, a value of 1 in a multiplexing mode, and/or a value of 2 in a dynamic RAT selection mode. The OMMA Controller 3900 may send the mode decision for a WTRU, for example, as shown in FIG. 42.

[0281] The interface between the OMMA Controller 3900 and the OMMA Scheduler 3910 may communicate a signal *Frag_Decision_Request_A11* that is used at the OMMA sender. The FBS module of the OMMA Scheduler 3910 (*e.g.*, where FBS is enabled, or both FBS and PBS are enabled) or the PBS module of the OMMA Scheduler 3910 (*e.g.*, where PBS is enabled) may inform the OMMA Controller 3900 (*e.g.*, Fragmentation Controller module) about the RATs selection, for example, when it takes a RATs selection decision for an IP packet.

[0282] The signal *Frag_Decision_Request_A11* may be aperiodic. The signal *Frag_Decision_Request_A11* may be used when the FBS or PBS takes a decision on a RATs selection for routing an IP packet. The signal may include a number of parameters, for example, the parameters described herein. A parameter *STA_Addr* may comprise an address of the WTRU for which parameters apply. A parameter *RAT_Id_List* may comprise a list of RAT IDs selected for each WTRU.

[0283] The interface between the OMMA Controller 3900 and the OMMA Scheduler 3910 may communicate a signal *Fragmentation_Decision_A12* that is used at the OMMA sender. The signal may be the response of *Frag_Decision_Request_A11* for corresponding IP packet. The OMMA Controller 3900 (*e.g.*, Fragmentation Controller module) may notify the

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Packet Fragment module of the OMMA Scheduler 3910 to enable or disable the fragmentation for that packet on the selected RAT.

[0284] The signal *Fragmentation_Decision_A12* may be aperiodic. The signal *Fragmentation_Decision_A12* may be used in response to *Frag_Decision_Request_A11*. The signal may include a number of parameters, for example, the parameters described herein. A parameter *STA_Addr* may comprise an address of the WTRU for which parameters apply. A parameter *RAT_Id_List* may comprise a list of RAT IDs for which a fragmentation decision is to be made. A parameter *Frag_Decision_List* may be an array (*e.g.*, *RAT1_Frag, ..., RATn_Frag*), for example, where *RATj_Frag* may take one of two values for the RATs given in *RAT_Id _List*: a 0 if fragmentation is off, and a 1 if fragmentation is on.

[0285] The interface between the OMMA layer and the RAT protocol stack may be described herein. FIG. 43 illustrates an example interface between an OMMA Controller and a RAT protocol stack. The OMMA Controller 4300 may communicate with the RAT Protocol Stack 4310 using interfaces A2 and A3. Using the interfaces A2 and/or A3, the OMMA layer may receive feedback metrics and RAT capability information from a RAT Protocol Stack 4310. Using the interfaces A2 and/or A3, the OMMA layer may reserve MAC resources on one or more RATs, for example, based on the requirements.

[0286] The interface between the OMMA Controller 4300 and the RAT Protocol Stack 4310 may communicate a signal *MAC Resource Reservation_A3* that may be used at the OMMA sender. The OMMA Controller 4300 (*e.g.*, Mac Resource Reservation module) may request to reserve resources (*e.g.*, x bandwidth for a fixed time duration "t") on one or more RATs.

[0287] The signal *MAC Resource Reservation_A3* may be aperiodic. The signal *MAC Resource Reservation_A3* may be used when the OMMA Controller needs to reserve resources on one or more RATs. The signal *MAC Resource Reservation_A3* may include a number of parameters, for example, *RAT_Id*, *STA_Addr*, *IP_QoS_Type,* and *Resource*. A parameter *RAT_Id* may identify the RAT on which a request may be sent. A parameter *STA_Addr* may comprise an address of the station for which the request was made. A parameter *IP_QoS_Type* may store a QoS Class for which the request was made. A parameter *Resource* may indicate resources that are to be reserved, for example, bandwidth and time.

[0288] The interface between the OMMA Controller 4300 and the RAT Protocol Stack 4310 may communicate a signal *System_Parameters_A3* that may be used at OMMA sender. The OMMA Controller 4300 (*e.g.,* Multi-RAT Multi-Band Device Discovery) may inform a RAT (*e.g.*, each RAT) about its RAT capability. This information may be used during discovery process to advertise WTRU RAT capability.

[0289] The signal *System_Parameters_A3* may be aperiodic. The signal *System_Parameters_A3* may be used when the WTRU boots up and/or for changes in the RAT capability. The signal *System_Parameters_A3* may include a *RAT_Id_List* parameter that may be an array of *RAT_Capability* (*e.g.*, *RAT1_Capability,...,RATn_Capability*).

[0290] The interface between the OMMA Controller 4300 and the RAT Protocol Stack 4310 may communicate a signal *RAT_Capabilities_A3* that may be used at the OMMA sender and/or the OMMA receiver. A RAT may inform/update the OMMA Controller 4300 (*e.g.*, Multi-RAT Multi-Band Device Discovery or RAT Update Management module) about RAT capabilities of associated WTRU/NT in case of, for example, a newly associated WTRU/NT. The RAT may inform the Multi-RAT Multi-Band Device Discovery module of the OMMA controller 4300. On the WTRU side, after listening to a beacon on the RAT for an already associated WTRU-NT pair, the RAT may inform the RAT Update Management module of the OMMA controller 4300. On the NT side, after receiving a *STA_RAT_Availability* message, the RAT may inform the RAT Update Management modul eof the OMMA controller 4300.

[0291] The signal *RAT_Capabilities_A3* may be aperiodic. The signal *RAT_Capabilities_A3* may be used when one or more of the events described herein occur. The signal *RAT_Capabilities_A3* may comprise one or more parameters, for example, an address *STA_Addr* of the WTRU and a parameter *RAT_Id_List* that may store an array of *RAT_Capability* (*e.g.*, *RAT1_Capability,...,RATn_Capabilityi)*.

[0292] The interface between the OMMA Controller 4300 and the RAT Protocol Stack 4310 may communicate a signal *Mode_to_Controller_A3* that may be used at the OMMA Receiver. The RAT may signal the OMMA Controller 4300 (*e.g.*, OMMA Mode Management module) regarding the mode, for example, which it has received in a beacon from a NT.

[0293] The signal *Mode_to_Controller_A3* may be aperiodic. The signal *Mode_to_Controller_A3* may be used when a RAT receives a new mode in a beacon. The signal *Mode_to_Controller_A3* may comprise one or more parameters (*e.g.*, *IP_QoS_Type*, *OMMA_Processing_Mode*, *OMMA_Scheduling_Scheme*, and *OMMA_Pkt_Dst_Mode*). A parameter *IP_QoS_Type* may store QoS Classes for which parameters may apply. A parameter *OMMA_Processing_Mode* may have a value of 0 if the OMMA processing mode is transparent and a value of 1 if the OMMA processing mode is non-transparent. A parameter *OMMA_Scheduling_Scheme* may have a value of 0 if the scheduling scheme is policy-based and a value of 1 if the scheduling scheme is feedback-based. A parameter *OMMA_Pkt_Dst_Mode* may have a value of 0 in a diversity mode, a value of 1 in a multiplexing mode, and/or a value of 2 in a dynamic RAT selection mode.

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[0294] The interface between the OMMA Controller 4300 and the RAT Protocol Stack 4310 may communicate a signal *Mode_to_RAT_A3* that may be used at the OMMA sender. The OMMA Controller 4300 (*e.g.*, OMMA Mode Management module) may signal a selected RAT about the mode, for example, which it may transfer in its beacon.

[0295] The signal *Mode_to_RAT_A3* may be aperiodic. The signal *Mode_to_RAT_A3* may be used when a new mode decision is made at the OMMA Controller 4300, for example, at a NT. The signal *Mode_to_RAT_A3* may comprise one or more parameters, for example, *STA_Addr*, *IP_QoS_Type*, *OMMA_Processing_Mode*, *OMMA_Scheduling_Scheme*, and *OMMA_Pkt_Dst_Mode*. An address *STA_Addr* may be the WTRU for which parameters may apply. A parameter *IP_QoS_Type* may store QoS Classes for which parameters may apply. A parameter *OMMA_Processing_Mode* may have a value of 0 if the OMMA processing mode is transparent and a value of 1 if the OMMA processing mode is non-transparent. A parameter *OMMA_Scheduling_Scheme* may have a value of 0 if the scheduling scheme is policy-based and a value of 1 if the scheduling scheme is feedback-based. A parameter *OMMA_Pkt_Dst_Mode* may have a value of 0 in a diversity mode, a value of 1 in a multiplexing mode, and/or a value of 2 in a dynamic RAT selection mode.

[0296] The interface between the OMMA Controller 4300 and the RAT Protocol Stack 4310 may communicate a signal *Max_RAT_Capabilities_A3* that may be used at the OMMA receiver. When a device (*e.g.*, WTRU) receives a maximum RAT capability advertisement of another device (*e.g.*, a NT) through a beacon request and/or a probe response on its RAT Protocol Stack, the device (*e.g.*, WTRU) may send information relating to the maximum RAT capability of the other device (*e.g.* NT) to the OMMA Controller 4300 (*e.g.*, Multi-RAT Multi-Band Device Discovery module), for example, to calculate the match with its own RAT that is used to complete initial discovery and association procedure.

[0297] The signal *Max_RAT_Capabilities_A3* may be aperiodic. The signal *Max_RAT_Capabilities_A3* may be used when a RAT Protocol Stack receives a beacon request and/or a probe response. The signal *Max_RAT_Capabilities_A3* may comprise one or more parameters, for example, an address *STA_Addr* of the WTRU and a parameter *RAT_Id_List* that may comprise an array of *RAT_Capability* (*e.g.*, *RAT1_Capability,...,RATn_Capability*).

[0298] The interface between the OMMA Controller 4300 and the RAT Protocol Stack 4310 may communicate a signal *Match_RAT_List_A3* that may be used at the OMMA Receiver. The OMMA Controller 4300 (*e.g.*, Multi-RAT Multi-Band Device Discovery module) may calculate the matched RATs for response to *Max_RAT_Capabilities_A3*. This information may be used to complete the initial discovery and association procedure.

[0299] The signal *Match_RAT_List_A3* may be aperiodic. The signal *Match_RAT_List_A3* may be generated as a response to the signal *Max_RAT_Capabilities_A3*. The signal *Match_RAT_List_A3* may comprise one or more parameters, for example, an address *STA_Addr* of the WTRU and a parameter *RAT_Id_List* that may comprise an array of matched *RAT_Capability* (*e.g.*, *RAT1_matched,...,RATn _matched*).

[0300] The interface between the OMMA Controller 4300 and the RAT Protocol Stack 4310 may communicate a signal *Feedback_Metrics_A2* that may be used at the OMMA sender. A RAT may send feedback metrics to the OMMA Controller 4300 (*e.g.*, Feedback WTRU Classifier module). The signal *Feedback_Metrics_A2* may be periodic, as this operation may be performed at predefined periodic intervals.

[0301] FIG. 44 is a diagram illustrating example feedback metrics that may be sent by a RAT (*e.g.*, each RAT). The signal *Feedback_Metrics_A2* may comprise one or more parameters, for example, an identifier *RAT_ID* that may identify the RAT that is sending feedback and an address *STA_Addr* for the WTRU for which parameters are sent. A parameter *IP_QoS_Type* may store QoS Classes for which parameters are sent. A metrics list *Metrics_List* may comprise one or more parameters, for example, a serving rate *Serving_Rate*, a *Jitter* parameter, an average packet delay *Avg_Pkt_Delay*, and a packet loss rate *Pkt_Loss_Rate*.

[0302] OMMA scheduler interfaces may be described herein. The OMMA Scheduler may communicate with the OMMA Controller, the Policy Database, and/or the RAT Capability Database. Interfaces with the OMMA Controller (*e.g.*, A5a, A5b, A9, A11 and A12) are described herein.

[0303] FIG. 45 is a functional block diagram depicting an example interface between an OMMA Scheduler and a RAT Capability Database. The OMMA Scheduler 4500 may communicate with the RAT Capability Database 4510 using interface A4. Through this interface, the OMMA scheduler 4500 may query the RAT capability database 4510 for RAT availability of a device (*e.g.*, an associated WTRU). The PBS and/or FBS modules of the OMMA scheduler 4500 may communicate with the RAT Capability Database 4510 through the A4 interface.

[0304] The A4 interface between the OMMA Scheduler 4500 and the RAT Capability Database 4510 may communicate a signal *STA RAT Capability Query_A4* that may be used at the OMMA Sender and/or the OMMA Receiver. The signal *STA RAT Capability Query_A4* may be used by the OMMA Scheduler 4510 (*e.g.*, PBS, FBS, or RAT Update Sender modules) to request the RAT Capability database 4510 for availability of RATs.

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[0305] The signal *STA RAT Capability Query_A4* may have aperiodic and/or periodic characteristics. For example, the PBS and/or FBS modules of the OMMA scheduler 4500 may transmit this query based on need. The RAT Update Sender module of the OMMA scheduler 4500 may transmit the query (*e.g.*, periodicallyi*)*. The signal *STA RAT Capability Query_A4* may comprise one or more parameters, for example, an address *STA_Addr* of the WTRU for which parameters are requested and a list *RAT_Id_List* of RAT Ids for which parameters are requested.

[0306] The interface between the OMMA Scheduler 4500 and the RAT Capability Database 4510 may communicate a signal *STA RAT Capability Response_A4* that may be used at the OMMA Sender and/or the OMMA Receiver. The RAT Capability database 4510 may respond to the *STA_RAT_Capability_Query_A4* by the OMMA Scheduler 4500 (*e.g.*, PBS, FBS, and RAT Update Sender modules) using this signal. The *STA_RAT_Capability_Query_A4* signal may comprise information of available RATs for a requested device (*e.g.*, WTRU).

[0307] The signal *STA RAT Capability Response_A4* may be aperiodic. The signal *STA RAT Capability Response_A4* may be generated in response to the signal *STA_RAT_Capability_Query_A4*. The signal *STA RAT Capability Response_A4* may comprise one or more parameters, for example, an address *STA_Addr* of the WTRU for which parameters are requested and a list *RAT_Id_List* of RAT Ids for which parameters are requested. The signal *STA RAT Capability Response_A4* may comprise an array *RAT_Info* of *RAT_Availability* comprising one or more elements (*e.g.*, corresponding to RAT Ids in the *RAT_Id_List* (*{RAT1_Availability},…, { RATn_Availability}*)).

[0308] FIG. 46 is a functional block diagram depicting an example interface between an OMMA Scheduler and a Policy Database. The OMMA Scheduler 4600 may communicate with the policy database 4610 using interface A6. Through interface A6, the PBS of the OMMA scheduler 4600 may query to access the predefined policies/rules (*e.g.*, the policies/rules described herein) in the Policy Database 4610.

[0309] The interface between the OMMA Scheduler 4600 and the Policy Database 4610 may communicate a signal *Policy_Query_A6* that may be used at the OMMA sender. The signal *Policy_Query_A6* may be used by the OMMA Scheduler 4600 (*e.g.*, PBS module) to request the Policy database 4610 for specific information regarding policies specific to a device (*e.g.*, WTRU) or to IP QoS traffic.

[0310] The signal *Policy_Query_A6* may be aperiodic. The signal *Policy_Query_A6* may be generated when the OMMA Scheduler (*e.g.*, PBS) needs policy information regarding a device (*e.g.*, WTRU) or IP QoS traffic. The signal *Policy_Query_A6* may comprise one or more

parameters, for example, an address *STA_Addr* of the WTRU for which parameters are requested and a parameter *IP_QoS_Type* that may store QoS Classes of IP packets for which parameters are requested.

[0311] The interface between the OMMA Scheduler 4600 and the policy database 4610 may communicate a signal *Policy_Response_A6* that may be used at the OMMA sender. The policy database 4610 may respond to the *Policy_Query_A6* by the OMMA Scheduler (*e.g.*, PBS) using this signal. This signal may comprise specific information regarding policies to be applied when serving a device (*e.g.*, WTRU) and IP QoS traffic.

[0312] The signal *Policy_Response_A6* may be aperiodic. The signal *Policy_Response_A6* may be generated in response to the signal *Policy_Query_A6*. The signal *Policy_Response_A6* may comprise one or more parameters, for example, an address *STA_Addr* of the WTRU for which parameters are requested and a parameter *IP_QoS_Type* that may store QoS Classes of IP packets for which parameters are requested. A parameter *Policy* may return information for a policy that is defined in the Policy Database 4610 for a given *IP_QoS_Type* of a given *STA_Addr*. If no such policy is defined, the parameter *Policy* may return a null value.

[0313] Within the OMMA Scheduler, modules may communicate with each other. FIG. 47 is a functional block diagram illustrating an example interface between a PBS module and an FBS module of an OMMA scheduler. The PBS 4700 may communicate with the FBS 4710 through interface A7. The PBS 4700 may transmit a RAT selection decision for an incoming IP packet.

[0314] The interface between the PBS 4700 and FBS 4710 modules may communicate a signal *RAT_Selection_Decision_A7* that may be used at the OMMA sender. For an incoming IP packet, the signal *RAT_Selection_Decision_A7* may be used by the PBS module 4700 to inform the FBS module 4710 about the RAT selection decision (*e.g.*, RAT Id in case of Single RAT selection and RAT priority list in case of multiple RAT selection scenario) based on one or more policies (*e.g.*, the policies/rules described herein).

[0315] The signal *RAT_Selection_Decision_A7* may be aperiodic. The signal *RAT_Selection_Decision_A7* may be generated when the PBS module 4700 receives a decision of RAT selection for an new incoming IP packet. The signal *RAT_Selection_Decision_A7* may comprise one or more parameters, for example, a parameter *IP_QoS_Type* that may store the QoS class of the IP packet for which a decision has been made. A parameter *RAT_Selection_List* may comprise the list of RATs in decreasing priority, *e.g.*, [RAT_2, RAT_4, RAT_1 …..]. In the case of a single RAT selection scenario, this parameter may be a single RAT, *e.g.*, [RAT_3].

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[0316] FIG. 48 is a functional block diagram depicting an example interface between an IP Packet QoS Identifier module and a PBS or FBS module within an OMMA Scheduler. The IP Packet QoS Identifier module 4800 may inform the PBS or FBS module 4810 about the QoS class type (*e.g.*, access category) of incoming IP packets, for example, through interface A14, for example, using a signal *QoS_Class_A14*. The signal *QoS_Class_A14* may be used at the OMMA sender. For an incoming IP packet, the signal *QoS_Class_A14* may be used by the IP Packet QoS Identifier module 4800 to inform the PBS or FBS module 4810 about the QoS Class type (*e.g.*, access category) of the incoming IP packet.

[0317] The signal *QoS_Class_A14* may be aperiodic. The signal *QoS_Class_A14* may be generated when the IP Packet QoS Identifier 4800 has a new incoming IP packet. The signal *QoS_Class_A14* may comprise one or more parameters, for example, an address *STA_Addr* of the WTRU for which the packet is incoming. A parameter *IP_QoS_Type* may store the QoS class (*e.g.*, access category) of the IP packet.

[0318] The Policy Database may interface with a DNS-APP entity. FIG. 49 is a functional block diagram illustrating an example implementation of an Ax interface between a Policy Database and a DNS-APP entity. The policy database 4910 may comprise one or more policies (*e.g.,* the policies/rules described herein) specific to certain domain names. A DNS-APP entity 4900 may reside just above the IP layer. A purpose of the DNS-APP entity 4900 may be to query (*e.g.*, periodically query) the policy database 4910 for domain names and resolve them into IP addresses. An interface Ax may be defined and used for this purpose.

[0319] There may be a conflict situation that occurs when a particular policy corresponding to a domain name is in use by the PBS module at the same time as the DNS-APP entity 4900 is accessing the policy database 4910 and changing the IP address corresponding to the policy in use. To avoid such a conflict scenario, a token for each domain name may be defined in the policy database. When the policy corresponding to a particular domain name is in use, the PBS module may set the token to "1" so that the DNS-APP entity 4900 may read the token and know that the policy is in use. If the token is set to "0," the policy may not be in use, and the DNS-APP entity 4900 can resolve the domain name to an IP address.

[0320] The policies within the Policy Database may be changed (*e.g.*, dynamically) based on user preference, for example, the RATs to be used for specific applications, *etc.* FIG. 50 is a functional block diagram illustrating an example implementation of an Ay interface between the Policy Database and a user interface application (UI-APP) entity. The Policy Database 5010 may interface with a user interface application (UI-APP) entity 5000 using an interface Ay. For example, a user of a device (*e.g.*, a WTRU) may set specific policies within the policy database.

[0321] If a user decides to add a new policy, the UI-APP entity 5000 may send a *set_policy* signal to the Policy Database 5010. The Policy Database 5010 may add a new entry in the database based on the (*e.g.*, type, criteria, and action) 3-tuple sent in the *set_policy* signal.

[0322] If a user decides to modify an existing policy, the UI-APP entity 5000 may send a *modify_policy* signal to the Policy Database 5010. The Policy Database 5010 may modify an existing entry in the database based on the (*e.g.*, type, criteria, and action) 3-tuple sent in the *modify_policy* signal.

[0323] FIG. 51 is a diagram illustrating an example of Multi-RAT Aggregation using OMMA Layer. As described herein, the OMMA layer 5100 may receive meta-data and/or link statistics feedback from one or more RATs 5110. A scheduler within the OMMA layer may be responsible for traffic shaping across the RATs 5110. At the sender side, traffic coming from the IP layer 5120 may be distributed across one or more RATs 5110 by the OMMA layer 5100, for example, based on the feedback associated with the RATs 5110, for example as illustrated in Figure 51. At the receiver side, traffic received from different RATs 5110 may be aggregated to be sent up to the IP layer 5120. This may be referred to as a multi RAT aggregation system.

[0324] The OMMA layer architecture may manage control plane and/or data plane processing capability. The OMMA layer 5100 may enable periodic RAT availability evaluation at terminals, and may store the information and use it for RAT selection. Fragmentation and reassembly in a multi-RAT system with unequal maximum transmission unit (MTU) sizes may be enabled by the OMMA layer 5100. The OMMA layer 5100 may be used to enable MAC resource reservation to achieve resource allocation across one or more RATs.

[0325] The OMMA layer 5100 may comprise one or more mechanisms to allocate IP packets over multiple RATs 5110 in multi-RAT systems, for example, to enable dynamic and opportunistic RAT selection and packet level aggregation. Traffic shaping by the OMMA layer 5100 may distribute IP packets across multiple RATs 5110. Implementations may be disclosed with reference to a single WTRU, single NT and single IP flow, and multiple UTs and multiple IP flows.

[0326] Packet scheduling of IP traffic over multiple RATs 5110 may be performed by the OMMA layer 5100. For example, a wireless system may include one or more network terminals (NTs) (*e.g.*, access points (APs), a Wi-Fi access point (AP), eNodeB, *etc.*) and one or more WTRUs (*e.g.*, a user terminal (UT), a Wi-Fi station, a STA, *etc.*). A NT and a WTRU may have the capability of supporting multiple RATs (*e.g.*, "K" RATs) where the RATs may operate on different spectral bands. The bands may be orthogonal. The signals on the one or more different bands may not interfere with each other. Transmitting terminals may operate in a OMMA

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multiplexing mode. At the NT, a stream of packets may be generated with an average packet arrival rate of x (*e.g.*, packets/unit time). The main stream may be split into K sub-streams. The sub-streams may be assigned to a corresponding transmit buffer associated with a RAT. The incoming traffic may be split across the K streams, for example, so as to minimize average end-to-end packet latency and/or out-of-order packet reception latency, which may maximize throughput.

[0327] Examples of single WTRU single IP flow cases may be described herein. When a single WTRU, a single NT, and single IP flow from a NT to WTRU is considered, the OMMA layer 5100 may determine how to distribute packets corresponding to the IP flow across RATs 5100, *e.g.*, such that the average end-to-end delay per packet may be minimized. Placing one or more packets in the transmit buffer associated with the RAT with the lowest latency may increase the average packet queuing delay. Dispersing the one or more packets across RATs 5100 randomly may decrease the average packet queuing delay and serving delay, however it may result in out-of-order reception of packets at the receiver due to differences in link latencies. This may cause longer queuing delays at the receiver to rearrange packets before sending them up to the IP layer 5120. The OMMA 5100 layer may comprise a packet assignment strategy that minimizes average end-to-end packet latency and/or out-of-order packet reception delay and maximizes throughput.

[0328] Examples of multi-WTRU multi-IP flow cases may be described herein. A system may comprise multiple WTRUs, a single NT, and multiple IP flows from the NT to one or more of the WTRUs. Although sender IP packets may be forwarded to the sender MAC layer as a single stream by the OMMA layer 5100, the MAC layer may sort them according to their corresponding access categories and/or WTRU addresses. The main IP stream for each WTRU may be split into multiple QoS streams that may be queued in separate buffers in the sender MAC layer. A buffer may correspond to an access category that may have a certain priority. This set up may complicate the traffic shaping because, for example, for each RAT 5110, the average packet delay may depend on the queuing delay and the latency of other packets in the same buffer. The average packet delay may also depend on the channel access by packets of the other buffers, which may be random. The channel access scheme that may be used to schedule medium access between different AC buffers may tie the waiting times for the packets in the buffers. The OMMA layer 5100 may comprise one or more modified packet assignment strategies (for example, as compared to the single WTRU, single IP flow case) that minimize average end-to-end packet latency.

[0329] The OMMA layer 5100 may comprise packet assignment implementations that may distribute IP packets across multiple RATs 5110, *e.g.*, to minimize average end-to-end latency per packet and/or maximize throughput for the case of a single NT, single WTRU, and single IP flow from NT to WTRU in the system.

[0330] The OMMA layer 5100 may comprise packet assignment implementations that may distribute IP packets across multiple RATs 5110, *e.g.*, to minimize average end-to-end latency per packet and/or maximize throughput for the case of multiple UTs, single NT and multiple IP flows from NT to each WTRU in the system.

[0331] The OMMA layer 5100 may comprise a leaky-bucket based smart packet assignment that may distribute IP schedule packets across multiple RATs 5110, *e.g.*, to minimize average end-to-end latency per packet and/or average out-of-order packet latency, and maximize throughput.

[0332] Criteria for the OMMA layer 5100 to adaptively select RATs for the communication based on, for example, link quality feedback metrics from the RAT may be described herein.

[0333] Enhancements to the OMMA layer architecture and signalling procedures to enable traffic management for the case of multiple UTs, single NT and multiple IP flows from NT to each WTRU in the system may be described herein.

[0334] Traffic shaping implementations at the OMMA layer 5100 to improve the system performance with TCP traffic may be described herein.

[0335] The OMMA layer 5100 may utilized feedback metrics, for example, such as but not limited to, average serving rate, average serving latency, second moment of average serving latency, average vacation time, second moment of average vacation time, *etc.*, that may be transmitted from a RAT protocol stack to an OMMA layer 5100 to enable packet assignment over multiple RATs 5110.

[0336] Criteria for the OMMA layer 5100 to adaptively select RATs 5110 for the communication based on link quality feedback metrics associated with the RAT may be described herein.

[0337] Leaky bucket based packet scheduling at an OMMA layer 5100, *e.g.*, to minimize average end-to-end latency per packet and/or average out-of-order packet latency, and maximize throughput may be described herein.

[0338] In the case of a multi-RAT network terminal, an OMMA layer 5100 may reside as a layer between RAT protocol stacks and the IP layer 5120. In this case, the feedback metrics

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disclosed herein may be a service access point (SAP) between a RAT and the OMMA layer 5100.

[0339] The OMMA layer 5100 (*e.g.*, entirely or partially) may reside as a logical entity on another device external to the multi-RAT network terminal (*e.g.*, a common gateway (GW)), which may have a wired network interface. For example, multiple single RAT network terminals may be distributed across a geographic area (*e.g.*, like a large enterprise) and the OMMA layer 5100 may reside on the common gateway (GW), which may have a wired network interface to the IP backhaul. The OMMA layer 5100 may reside in the GW. For example, one or more functions of the OMMA layer 5100 may reside in the gateway, while the rest may be within the network terminals. If the physical interface is wireless, one or more of the feedback metrics carried over the wireless interface between GW and network terminals may be standardizable and/or detectable.

[0340] Packet assignment for single WTRU single IP flow may be described herein. For example, there may be a single NT and a single WTRU in a system. A QoS class of IP packets may be served. For example, K may be the number of available RATs supported by the NT and/or WTRU. One or more K RATs may operate on different spectral bands. The bands may be orthogonal. Signals on the different bands may not interfere with one another.

[0341] At the NT, a stream of packets may be generated in a Poisson fashion with an average packet arrival rate x (packets/unit time). The main stream may be split into K sub-streams. The sub-streams may be assigned to a corresponding transmit buffer in each RAT. For example, the i^{th} sub-stream, i = {1,…,K} may be Poisson with an average arrival rate xi (packets/unit time) where:

$$x = \sum_{i=1}^{K} x_i.$$

[0342] The multi-RAT system in a terminal device may be modeled as K parallel M/M/1 queues, *e.g.*, to account for that there may be K servers. One or more of the servers may have a different serving rate. Packets may be transmitted over channel i in a first-come first-served (FCFS) basis and may be sent successfully at serving rate R_i (packets/unit time). The constraint listed below may be imposed (*e.g.*, to assure system stability):

$$\sum_{i=1}^{K} R_i > x.$$

[0343] Rate R_i may reflect the quality of channel i and may be fed back from a RAT (*e.g.*, each RAT) to the transmitting OMMA layer, for example, to update its traffic shaping strategy. At the receiver, the sub-streams may be combined in the receiving OMMA layer. An

OMMA layer at the sender may identify and/or maintain the average rates x_i based on the feedback metric R_i. This may minimize average end-to-end latency per packet and/or maximum throughput.

[0344] The x_i^* (*e.g.*, which may be an optimal x_i^*) may be expressed as:

$$x_i^* = \frac{\sum_{j=1, j\neq i}^{K} \sqrt{R_j} R_i - \sqrt{R_i} \sum_{j=1, j\neq i}^{K} R_j + \sqrt{R_i} x}{\sum_{i=1}^{K} \sqrt{R_i}}$$

where R_i may be the average serving rate of a RAT_i feedback to the OMMA layer.

[0345] Feedback metrics for single WTRU single IP flow cases may be described herein. R_i may be the effective rate of packets being transmitted through RAT_i of the transmitter and/or received successfully at the receiver. For example, this rate may be captured at the transmitter's RATs by observing ACKs indicating successful packet delivery. R_i may be calculated as $\frac{1}{T}$, where T may be the average serving latency per packet at the RAT. T may be defined as the time duration from t_0 to t_1. t_0 may be the moment when MAC starts to perform channel contention process (*e.g.*, CSMA/CA) for that packet. t_1 may be the moment when ACK for that whole packet is received at the MAC layer of the sender node.

[0346] T may be counted as the total time duration that a MAC layer associated with a RAT "serves" that packet to send it out. T may include a retransmission delay if a packet needs to be retransmitted. A MAC queuing delay may not be included in T.

[0347] Criterion for RAT selection vs. aggregation may be described herein. Comparing the value of x_i^* expression with 0 may give a threshold, which may be used as a switching criterion between a selection mode and multiplexing mode. For example, FIG. 52 is a diagram illustrating an example of a threshold for mode selection in two RAT systems. A threshold for the OMMA layer to decide an operating mode for two-RAT systems may be described herein.

[0348] The OMMA layer may rely on the value of total arrival rate x and the value of $\sqrt{R_1 R_2} - R_2$ (*e.g.*, assuming $R_1 \geq R_2$), for example, to adaptively decide the operation mode. For example, when $0 < x \leq \sqrt{R_1 R_2} - R_2$, the OMMA layer may switch to single RAT selection mode (*e.g.*, data transmitting may be limited on RAT 1). For example, when $\sqrt{R_1 R_2} - R_2 < x < R_1 + R_2$, the OMMA layer may switch to a multiplexing mode (*e.g.*, data may be sent on both RATs). The data allocation with a single WTRU may be deployed on downlink with a single WTRU, for example, it may be deployed on the uplink where data may be scheduled on different RATs at a WTRU to send to a NT.

[0349] Packet assignment for multi-WTRU multi-IP flow (QoS) may be described herein. For example, a NT may communicate substantially simultaneously with multiple UTs

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(*e.g.*, as illustrated in FIG. 53). Multiple IP flows belonging to different QoS classes may be served by the NT-WTRU links (*e.g.*, each NT-WTRU link), where each IP flow may have different packet delay and/or throughput requirements.

[0350] Referring back to FIG. 3, a diagram illustrating an example of a single network terminal and multi user terminals is provided. The OMMA layer (*e.g.*, the OMMA layer 303 at the NT 301 and/or the OMMA layer 310 at a WTRU 315) may determine the traffic distribution across RATs for one or more IP flows and/or for one or more NT-WTRU links. The traffic distribution may be optimized. The data allocation based on this traffic ratio may minimize the average packet latency and/or may maximize total throughput. At the NT 301, one or more RAT's meta-data and/or link quality metrics may be measured for each AC and/or each WTRU 310. The meta-data and/or link quality metrics may be fed back to the OMMA layer 303.

[0351] Although sender IP packets may be forwarded to the sender MAC layer as a single stream, the MAC layer may sort them according to their corresponding access categories and/or WTRU addresses. The main IP stream for each WTRU 310 may be split into one or more QoS streams that may be queued in separate buffers in the sender MAC layer. Each buffer may correspond to an access category that has a certain priority. This may complicate the traffic shaping because the average packet delay may depend on the queuing delay, the latency on each RAT, and/or the channel access by packets of the other buffers, which may be random. The channel access scheme that may be used to schedule medium access between different AC buffers may tie the waiting times for the packets in the buffers.

[0352] Q_{ik} may denote the transmission buffer to store data destined for WTRU "i" for IP flow "k" (*e.g.*, or access category k). Because of the nature of the queuing and contention process in multi QoS supported system (*e.g.*, EDCA mode), each queue Q_{ik} may be modeled as a M/G/1 queue with vacations. A vacation may refer to a time when the server may go on "vacations" for some random period of time, for example, at the end of each serving period for queue Q_{ik}. The vacation time with queue Q_{ik} may be the duration NT serves other WTRUs (*e.g.*, not the WTRU i) and/or NT sends data of other IP flows or access categories (*e.g.*, does not serve the IP flow k or access category k). The OMMA layer 300 may utilize the queuing implementations, for example, to effectively allocate data for each IP flow toward each WTRU 310, for example, independently.

[0353] Examples of feedback metrics for multi WTRU multi IP flow (QoS) cases may be described herein. Table 6 illustrates examples of feedback metrics to support multi-WTRU multi QoS configurations. The subscripts i and k may have been omitted in the terminologies below. A term below may correspond to one IP flow k or access category k from a NT to a WTRU i.

Table 6: Feedback Metrics

R_j	Average serving rate at RAT j of NT as described herein
$\overline{T_j}$	The average serving time at RAT j of NT
$\overline{T_j^2}$	The average second moment of serving time at RAT j of NT
$\overline{V_j}$	The average vacation time of the queue Q_{jk} at RAT j, which may be the time interval between two period RAT j of NT serving queue Q_{jk} to send out data. This may be the average duration RAT j of NT serving other UTs (≠j) and/or sending data of other ACs (≠k) before back to serving queue Q_{jk}
$\overline{V_j^2}$	Second moment of the average vacation time of queue Q_{jk} at RAT j

[0354] The average system delay across *K* RATs that may be minimized may be:

$$F = \frac{\sum_{j=1}^{K}\left(\left(\frac{x_j\overline{T_j^2}}{2(1-\frac{x_j}{R_j})}+\frac{\overline{V_j^2}}{2\overline{V_j}}+\frac{1}{R_j}\right)*x_j\right)}{x}$$

[0355] The arrival rate packets for RAT *j* may be:

$$x_j^* = \left(R_j \pm \frac{R_j^2\sqrt{\overline{V_j}\,\overline{T_j^2}}}{\sqrt{R_j^2\overline{V_j}\,\overline{T_j^2}-R_j\overline{V_j^2}+(2x\gamma R_j-2)\overline{V_j}}}\right)$$

Where

$$\gamma \approx \frac{\left(\sum_{j=1}^{K}\mp R_j^{\frac{3}{2}}\right)^2}{2x\left(\sum_{j=1}^{K}R_j-x\right)^2}$$

[0356] For example, up to 2M different combinations of the sign ± in the above equations may be used. The OMMA transmitter may use the feedback metrics from a RAT (*e.g.*, as in Table 6) to determine the instantaneous ratio of distribution of packets across the RATs based on, for example, the formulation above.

[0357] OMMA layer based smart packet scheduling may be described herein. FIG. 53 is a diagram illustrating an example of a packet reordering scenario. FIG. 54 is a diagram illustrating another example of a packet reordering scenario. For example, reordering delay D_n for each packet n may be defined as the time packet n waits at the OMMA layer of the receiver

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node for the earlier packets coming to the receiver (*e.g.*, packets with the order smaller than n coming successfully to the OMMA layer of the receiver node). This may occur when data packets are received out of order. Packets may be received out of order when they traverse each link with different packet latency. At the transmitter side, packets of the main stream may be split into multiple sub streams for transmission over different links, which may have different latencies. As the OMMA layer at the receiver receives packets one after the other, it may send the packets to the IP layer in an order. Some packets may be held at the OMMA layer for reordering purpose, which may incur a reordering delay.

[0358] In an example, a packet of index $n \in \{1,\ldots, N\}$ may be transmitted over RAT j, according to a probability $\frac{x_j}{x}$, where $\sum_{j=1}^{K} \frac{x_j}{x} = 1$. This packet may experience a certain delay. Upon reception, the packet may be given an index $n + \varepsilon$, where $\varepsilon \in \{-N+1,\ldots, N-2, N-1\}$ may be the ordering offset. A packet may be referred to as being received in the correct order if $\varepsilon = 0$. Otherwise, a packet may be referred to as offset. A reordering delay may occur when packets with lower indices are received late and/or when packets with higher indices are received early. This may happen in one or more circumstances. For example, a reordering delay may occur if a packet n is transmitted over the link with higher latency whereas δ subsequent packets are transmitted over the lower latency link, for example as illustrated in FIG. 53. A reordering delay may occur if a packet n is transmitted over the link with lower latency whereas δ preceding packets are transmitted over the higher latency link, for example as illustrated in FIG. 54.

[0359] If packet n is scheduled to be transmitted over a faster link than the packets after packet n and before packet n- δ in the transmitter's main queue, a reordering issue may not occur, for example, regardless of their RAT assignment. If packet n is scheduled to be transmitted over a slower link than the packets before packet n and after packet n+ δ in the transmitter's main queue, a reordering issue may not occur, for example, regardless of their RAT assignment (*e.g.*, as shown in FIG. **Error! Reference source not found.**53 and FIG. 54).

[0360] FIG. 55a is a diagram illustrating an example of a random assignment of packets. FIG. 55b is a diagram illustrating an example of a smart assignment of packets across RATs. For example as shown in FIG. 55a, if seven IP packets are transmitted and IP packets with IDs #1, #2, #3 and #5 are received (*e.g.*, at a given time), then the OMMA layer may send packets #1, #2 and #3 to the IP layer and may wait for packet #4 to arrive before sending packets #5. This may cause a reordering delay for packet #5. The other four IP packets may not suffer this delay.

[0361] This may have an impact on UDP and/or TCP applications. For example, the QoS of real-time UDP applications, such as but not limited to voice over IP and/or live video

streaming, may suffer. Real-time UDP applications may suffer because out of order packets may be counted as lost packets and may be ignored at the receiver side. For TCP, packets out of order may generate a duplicate ACK issue, which may trigger unnecessary congestion control that may reduce end to end throughput.

[0362] A potential cause may be placing packets with a higher ID in a shorter queue (*e.g.*, smaller queuing delay) while other packets with a lower ID may be placed in a longer queue (*e.g.*, bigger queuing delay). A potential cause may be when packets with a lower index are transmitted over slower links, while packets with a higher index are sent over faster links. A packet assignment strategy at the OMMA transmitter side may attempt to maintain the correct ordering of packet reception at the receiving end, such that the ordering delay may be minimized, for example, as shown in FIG. **Error! Reference source not found.**55b.

[0363] Referring to FIG. **Error! Reference source not found.**55a, an example configuration where a random assignment of packets may result in packet reordering delays at the receiving end is illustrated. This may be avoided via packet assignment strategies at the transmitting end, for example, as shown in the example of FIG. 55b.

[0364] FIG. 56 is a representation of an example OMMA layer smart packet allocation. FIG. 56, which may be referred to as a leaky bucket implementation, may be a smart packet assignment that may minimize the average end-to-end latency per packet and/or minimize the out-of-order packet reception at the receiver for multi RAT aggregation. Simulations (*e.g.*, OPNET simulations) may show the gains that this scheme may provide compared to other schemes, such as but not limited to, 50%-50% distributions of packets across two RATs and/or distribution of packets based on individual serving rates of RATs.

[0365] The example of FIG. 56 may maintain K token variables. There may be one token variable for each RAT. The token for each RAT may be assigned to be 0 (*e.g.*, initially). The token for each RAT i may be incremented iteratively by $\frac{x_i}{x}$, where x_i may be the optimal rate for RAT i calculated in the last section, until one or more of the tokens exceeds 1. The RAT corresponding to the token that exceeds 1 may be selected to send the next incoming unscheduled packet at the OMMA layer. This token may be decremented by 1 and the process of incrementing tokens may be continued. This may run "ahead" of packets arriving at the OMMA layer (*e.g.*, the OMMA layer may know which packet ID may be scheduled on which RAT). Since the x_i s may be chosen so as to minimize the average system delay per packet, a leaky bucket implementation may ensure that the RAT chosen to send a packet may be such that each packet experiences the minimum delay and/or arrives in the correct order with respect to its preceding and succeeding packets at the receiver.

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[0366] The OMMA layer may perform a method of aggregating bandwidth available on multiple radio access technologies (RATs), for example, using a leaky bucket implementation. For example, the OMMA layer may assign a variable to each of a plurality of RATs. The OMMA layer may increment each of the plurality of variables at a rate. The rate related to an estimated arrival rate of a packet transmitted across the RAT to which the variable is assigned. The OMMA layer may determine that a variable of the plurality of variables is greater than or equal to one. The OMMA layer may transmit a packet across the RAT whose variable is greater than or equal to one. The OMMA layer may decrease the variable that is greater than or equal to one by one. The OMMA layer may continue to increment each of the plurality of variable at a rate, for example, until another variable is greater than or equal to one. The OMMA layer may send a packet across the RAT whose variable is greater than or equal to one, and decrease that variable by one. The OMMA layer may continue this implementation until all packets of an IP flow have been sent across the RATs.

[0367] The OMMA layer may perform a method of aggregating bandwidth available on multiple radio access technologies (RATs), for example, using a leaky bucket implementation. For example, the OMMA layer may have two or more associated RATs. The OMMA layer may assign a first variable to a first RAT and a second variable to a second RAT. The OMMA layer may increment the first variable of the first RAT by a first rate and increment the second variable of the second RAT by a second rate. The first rate may be related to an estimated arrival rate of a packet transmitted across the first RAT. The second rate related to an estimated arrival rate of a packet transmitted across the second RAT. The OMMA layer may determine that the first variable is greater than or equal to one, wherein the second variable is less than one. The OMMA layer may send a packet across the first RAT. The OMMA layer may decrease the first variable by one. The OMMA layer may continue the implementation until all packets of an IP flow have been sent across the RATs.

[0368] FIG. 57 is a graph illustrating an example of measurements of average reordering delay per packet for different scheduling implementations. Different scheduling implementations at the OMMA layer of the sender node with different SNR levels at the PHY layer of a receiver node on each RAT may be deployed. The reordering delay at the receiver side may be measured, for example, as shown in FIG. 57. The leaky bucket implementation (*e.g.*, as shown in FIG. 56) may be simulated and compared with other implementations which, for example, may schedule packets in random order but with predefined average percentage distribution across RATs. The leaky bucket implementation may outperform the other implementations. The single RAT selection (*e.g.*, the results of which may be shown in FIG. 57)

may be for reference. The single RAT selection (*e.g.*, the results of which may be shown in FIG. 57) may use one RAT and may not experience any reordering issue.

[0369] Managing TCP traffic at the OMMA layer may be described herein. A congestion control and flow control mechanism may be triggered due to the packet loss and/or packet out of order over multiples RATs, for example, for TCP traffic. One or more of the following implementations may be used, *e.g.*, to effectively handle UDP and/or TCP traffic, where such use may be in combination with other implementation(s) described herein. At the OMMA layer of the sender node, the OMMA layer may analyze the TCP header of an incoming packet to identify the beginning and/or the end of each TCP connection. At the beginning of the TCP transmission, the OMMA layer may route traffic to send over a single RAT (*e.g.*, single RAT selection mode). This may help the TCP flow control ramp up to the stable stage before the OMMA layer may make the decision to switch to a multiplexing mode and/or RAT selection mode. The OMMA layer may analyze the TCP header to manage the beginning and/or the end of each TCP connection. The OMMA layer may deploy smart packet scheduling, *e.g.*, as described herein, for each TCP flow and/or for combined TCP flows. A buffer may be deployed at the OMMA layer of the receiver. One function of this buffer may be for reordering purpose. Packets received out of order may be temporarily stored in this buffer. There may be a maximum duration for which packets may stay in the buffers (*e.g.*, a few milliseconds). The packets may pop out of the buffer no later than this duration. This period of time may limit the sizes of the buffers. The TCP ACK packets sent back from the receiver may be allocated the highest priority and may be sent on the fastest and/or highest quality RAT at the time. This may ensure that the TCP ACK packets gets back as early as possible and in the correct order. ACK packets may have small sizes and may experience small packet latencies.

[0370] Various processing may occur for arriving TCP ACK packets at the OMMA layer of the sender. If the received packet at the OMMA sender is not a duplicate ACK, the OMMA layer may forward the ACK to upper layer as soon as it arrives. If the received packet is a duplicate ACK, the OMMA layer may buffer the third or later duplicate ACKs for a short period of time (*e.g.*, a few milliseconds) before sending them to the upper layer. If an arrived packet is an ACK with later index than the duplicate ACK currently buffered, the OMMA layer may drop the duplicate ACK and send the most recent ACK to the upper layer. Since the third duplicate ACK that comes to sender may trigger the congestion control mechanism by reducing the sending rate (*e.g.*, which may be significant), holding back this ACK may give more time for the data to get to the receiver successfully, for example, when latencies across the RATs are different. This may minimize an unnecessary congestion control mechanism to be triggered.

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[0371] Procedures to enable Multi-WTRU Multi IP flow traffic management in an OMMA layer may be described herein. An example scenario of multiple WTRUs and a single NT in a system supporting multiple IP flows of different QoS classes from NT to WTRU in the system may be described herein. Each NT-WTRU link may be configured to operate using multiple RATs at any given time.

[0372] To support multiple WTRUs, each with multiple IP flows, the OMMA layer may comprise an OMMA Scheduler for each associated WTRU. It may comprise an IP Packet WTRU Classifier to read the WTRU address of the packet and/or send the packet to the OMMA scheduler corresponding to that WTRU. The OMMA Scheduler for each associated WTRU may comprise one or more Feedback Based Schedulers (FBSs) (*e.g.*, separate FBS to handle IP flow of one QoS class (Access Category)). The OMMA scheduler may comprise an IP Packet QoS Identifier to identify the QoS class for incoming IP packet and/or to send it to corresponding FBS.

[0373] The OMMA Controller may comprise a Feedback WTRU Classifier to classify feedback metrics based on the WTRU address to send feedback metrics to OMMA Scheduler of corresponding WTRU. The OMMA Controller may comprise a Feedback QoS Classifier which may classify the feedback metrics based on the QoS class. These feedback metrics may be sent to appropriate FBS dedicated for that QoS class on the chosen OMMA Scheduler by Feedback WTRU Classifier.

[0374] FIG. 58 is a diagram illustrating an example of an OMMA Sender at NT for single RAT selection for Multi WTRU Multi IP Flow. An example of the OMMA layer at the sender is shown in FIG. 58 (*e.g.*, at a NT when data traffic flows in the downlink direction from the NT to a WTRU, or at a WTRU when data traffic flows in the uplink direction from the WTRU to a NT).

[0375] Traffic routing at the OMMA sender may include one or more of the following. IP packets may arrive at IP Packet WTRU Classifier of the OMMA layer. IP Packet WTRU Classifier may forward the IP packet to a corresponding OMMA Scheduler based on WTRU address. At the OMMA Scheduler, the IP packets may be sent to an IP Packet QoS Identifier. The IP Packet QoS Identifier may forward the IP packet to FBS of the corresponding QoS class (*e.g.*, access category).

[0376] FBS may make a decision on RAT selection based on the RAT capability provided by the Capability Database using the A4 interface and/or feedback provided from the OMMA Controller for the IP flow's access category using the A5a interface. RAT_Metrics_FBS_A5a signal of the A5a interface may include of one or more of the following

parameters: RAT_Id, which may provide the RAT Ids of the enabled RATs; STA_Addr, which may provide the address of the WTRU for which the parameters may apply; IP_QoS_Type, which may provide QoS Classes (*e.g.*, access category) for which feedback may be available; Metrics, which may comprise one or more of the following parameters for each QoS class (*e.g.*, access category) given in IP_QoS_Type for the RATs given in RAT_Id vector for the WTRU given in STA_Addr: Arrival_Rate; Serving_Rate; and/or Avg_Pkt_Delay. It may choose one or more of the RATs capable for that WTRU, for example, at cold-start.

[0377] Based on the final decision on RAT selection, the FBS may distribute incoming IP packets across the selected RATs (*e.g.*, optimally) so as to, for example, minimize average end-to-end delay per packet and/or minimize out-of-order packet reception. The FBS may forward the packets to the Packet Fragmentation module (*e.g.*, if enabled) of the selected RATs. The FBS may send a decision of the selected RATs to the Fragmentation Controller module of the OMMA Controller, for example, vai the A11 interface. A Frag_Decision_Request_A11 signal on A11 interface may include, for example, STA_Addr, which may provide an address of the WTRU for which request has been made, and/or RAT_Id_List, which may comprise one or more of the RAT Ids of the selected RATs.

[0378] A Fragmentation Controller may make a decision of fragmentation based on, for example, the request made through the A11 interface. If the fragmentation controller does not have MTU information of the selected RAT, the fragmentation controller may communicate with an Capability Database to receive MTU information, for example, using the A1 interface. Signal STA_RAT_Capability_Query_A1 on the A1 interface may include STA_Addr, which may provide an address of the WTRU for which request has been made, and/or RAT_Id_List, which may comprise one or more of the RAT Ids of the selected RATs. The capability database may send the response to the above request, for example, through the same interface A1. Signal STA_RAT_capability_Response_A1 on the A1 interface may include of one or more of the following parameters: STA_Addr, which may provide an address of the WTRU for which request has been made; RAT_Id_List, which may comprise the RAT Ids of the selected RATs; and/or RAT_Info, which may provide an array of 3-tuples (*e.g.*, MTU, Max_RAT_Capability, RAT_Availability) for the RAT_Id of the selected RATs (*e.g.*, specified in RAT_Id_List).

[0379] A Packet Fragmentation module of the selected RATs may receive the decision of fragmenting or not fragmenting the incoming packet from the FBS, for example, based on the fragmentation decision received from Fragmentation Controller through interface A12. Signal *Fragmentation_Decision_A12* on A12 interface may include of one or more of the following parameters: *STA_Addr*, which may provide an address of the WTRU for which request has been

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made; *RAT_Id_List*, which may comprise the RAT Ids of the selected RATs; and/or *Frag_Decision_List*, which may comprise the decision for fragmentation for the selected RAT using, for example, '0' to indicate Fragmentation OFF and '1' to indicate Fragmentation ON. This may be performed after that packets/fragments may be sent to the RAT.

[0380] A RAT switch may occur when a selected RAT is unable to fulfill a requirement of given IP flow QoS Class. When FBS detects this situation, it may query the WTRU RAT Capability Database for RAT availability information through, for example, the STA_RAT_Capability_Query_A4 signal on the A4 interface. After receiving a list of RATs that may be available for the WTRU (*e.g.*, through STA_RAT_Capability_Response_A4 signal on A4 interface), the FBS may select an unused RAT from the RAT availability list to replace the above RAT (*e.g.*, which may not be able to fulfill the QoS requirement).

[0381] When a RAT switch occurs, the FBS may duplicate one or more packets across one or more RATs (*e.g.*, two RAT, for example, a RAT which is not able to fulfil the QoS requirement and a RAT chosen to replace this RAT) to enable a soft handover across RATs and/or avoid out-of-order packet reception at OMMA receiver.

[0382] FIG. 59 is a diagram illustrating an example call flow comprising one or more of the implementations described herein.

[0383] As described herein, a node (e.g., a NT or a WTRU) comprising an OMMA layer may aggregate bandwidth available on RATs. The node may establish a communication path via one or more RATs. The OMMA layer of the node may comprise a controller in operable communication with one or more RATs, and a scheduler in operable communication with one or more RATs. For example, the controller and scheduler may be in operable communication with a first RAT and a second RAT. The controller may be configured to determine a time duration and a bandwidth requirement of an IP packet. For example, the controller may be configured to determine a first time duration and a first bandwidth requirement for a first IP packet, and determine a second time duration and a second bandwidth requirement for a second IP packet. The first IP packet and the second IP packet may be part of an IP flow addressed to a receiving node (*e.g.*, a NT or a WTRU). For example, the IP flow may be associated with a single application. For example, the node may be a NT and the receiving node may be a WTRU, or the node may be a WTRU and the receiving node may be a NT.

[0384] The controller may be configured to request resources on the one or more RATs. For example, the controller may be configured to request resources on the first RAT and the second RAT based on the first time duration and the first bandwidth requirement for the first IP

packet and based on the second time duration and second bandwidth requirement for the second IP packet. The controller may be configured to send instructions to the scheduler.

[0385] The scheduler may be configured to receive feedback information associated with the one or more RATs. For example, the scheduler may be configured to receive first feedback information associated with the first RAT, and receive second feedback information associated with the second RAT. The scheduler may be configured to determine to send one or more IP packets via the one or more RATs (*e.g.*, according to the implementations described herein). For example, the scheduler may be configured to determine to send the first IP packet via the first RAT according to the first and second feedback information and the instructions, and determine to send the second IP packet via the second RAT according to the first and second feedback information and the instructions. The scheduler may be configured to send one or more IP packets via one or more RATs. For example, the scheduler may be configured to send the first IP packet via the first RAT, and send the second IP packet via the second RAT.

[0386] As described herein, the OMMA layer may be utilized to aggregate IP packets into an IP flow. The OMMA layer may receive one or more IP packets from one or more RATs. For example, the OMMA layer may receive a first IP packet via a first RAT, and receive a second IP packet via a second RAT. For example, the first RAT may be associated with a first license exempt (LE) band channel, and the second RAT may be associated with a second LE band channel. The OMMA layer may aggregate on or more IP packets into an IP flow. For example, the OMMA layer may aggregate the first IP packet and second IP packet to recreate an IP flow. The IP flow may be associated with a single application.

[0387] For example, the OMMA layer may receive a third IP packet via a third RAT. The third RAT may be associated with a WiFi channel. The OMMA layer may aggregate the first IP packet, the second IP packet, and the third IP packet to recreate the IP flow. Further, the OMMA layer may create headers for one or more IP packets. The headers may relate to the order of the IP packets within the IP flow. For example, the first IP packet may comprise a first header and the second IP packet may comprise a second header (*e.g.*, which may have been created by the OMMA layer). The first header and the second header may relate to an order of IP packets of the IP flow.

[0388] Although features and elements are described above in particular combinations, one of ordinary skill in the art will appreciate that each feature or element can be used alone or in any combination with the other features and elements. In addition, the methods described herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable medium for execution by a computer or processor. Examples of computer-readable

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media include electronic signals (transmitted over wired or wireless connections) and computer-readable storage media. Examples of computer-readable storage media include, but are not limited to, a read only memory (ROM), a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks (DVDs). A processor in association with software may be used to implement a radio frequency transceiver for use in a WTRU, UE, terminal, base station, RNC, or any host computer.

What is Claimed:

1. A method of aggregating bandwidth available on multiple radio access technologies (RATs), the method comprising:

receiving first feedback information associated with a first RAT;

receiving second feedback information associated with a second RAT;

determining a first IP packet to send via the first RAT according to the first and second feedback information;

determining a second IP packet to send via the second RAT according to the first and second feedback information, wherein the first and second IP packets are part of an Internet Protocol (IP) flow addressed to a node;

sending the first IP packet via the first RAT; and

sending the second IP packet via the second RAT.

2. The method of claim 1, further comprising:

establishing a first communication path via the first RAT associated with the node; and

establishing a second communication path via the second RAT associated with the node.

3. The method of claim 1, wherein the IP flow is associated with a single application.

4. The method of claim 1, wherein the node is an access point (AP).

5. The method of claim 1, wherein the node is a wireless transmit/receive unit (WTRU).

6. The method of claim 1, wherein each of the first feedback information and the second feedback information comprise at least one of a medium access delay, a frame error rate, an average data rate, a received signal strength indication (RSSI), queuing latency per access category per RAT, end-to-end latency, a backoff time, a number of channels, channel bandwidth, a media access control (MAC) type, MAC aggregation support, an access category, a transmission opportunity (TXOP) duration, an estimated arrival rate of a packet, an average serving rate, an average serving latency, a second moment of average serving latency, an average vacation time, a second average of vacation time, or a transmission control protocol (TCP) parameter.

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7. The method of claim 1, wherein the first feedback information and the second feedback information are received via at least one of of an A2 interface, an A3 interface, an A5a interface, or an A5b interface.

8. The method of claim 1, wherein determining to send the first IP packet via the first RAT and the second IP packet via the second RAT is determined further according to at least one rule, the at least one rule comprising a quality of service (QoS) class rule.

9. The method of claim 8, wherein the at least one rule further comprises at least one of a device capability rule, an operator policy rule, an IP packet flow rule, a device coordinate rule, a source domain rule, a source IP address rule, a destination domain rule, a destination IP address rule, IP protocol rule, a port number rule, a subscriber priority rule, a link quality rule, a charging rule, or a security rule.

10. The method of claim 1, further comprising:

determining a time duration and a bandwidth requirement for the IP flow; and

requesting resources on the first RAT and on the second RAT based on the time duration and the bandwidth requirement for the first IP packet and the second IP packet, wherein the resources are characterized by the time duration and the bandwidth requirement.

11. The method of claim 10, further comprising:

receiving a quality of service (QoS) of the first IP packet and a QoS of the second IP packet, wherein the resources on the first RAT and on the second RAT are requested based further on at least one of the first feedback information, the second feedback information, the QoS of the first IP packet, and the QoS of the second IP packet.

12. The method of claim 10, wherein the resources are requested on the first RAT and on the second RAT using at least one of an A1 interface or an A2 interface.

13. The method of claim 1, further comprising:

receiving first maximum transmit unit (MTU) information associated with the first RAT;

receiving second MTU information associated with the second RAT;

receiving packet size information associated with the first IP packet;

receiving packet size information associated with the second IP packet;

adjusting at least one of a size of a MTU of the first IP packet or a size of a MTU of the second IP packet based on the first MTU information and the second MTU information.

14. The method of claim 13, wherein the size of the MTU of the first packet is different from the size of the MTU of the second packet.

15. The method of claim 13, wherein the size of the MTU of the first packet is the same as the size of the MTU of the second packet.

16. The method of claim 1, wherein the node a multi-RAT node, the method further comprising:

receiving a signal from the multi-RAT node, the signal being characterized by a plurality of available RATs of the multi-RAT node.

17. The method of claim 1, wherein determining to send the first IP packet via the first RAT and the second IP packet via the second RAT is determined further according to a packet distribution mode.

18. The method of claim 17, wherein the packet distribution mode is at least one of diversity mode, multiplexing mode, hybrid mode, or dynamic RAT selection mode.

19. The method of claim 1, further comprising:

determining whether channel quality of the first RAT is below a threshold;

upon determining that the channel quality of the first RAT is below the threshold, duplicating the first IP packet to create a first instance of the first IP packet and a second instance of the first IP packet;

sending the first instance of the first IP packet via the first RAT; and

sending the second instance of the first IP packet via a third RAT.

20. The method of claim 19, further comprising:

determining whether channel quality of the second RAT is at or above the threshold; and

upon determining that the channel quality of the second RAT is at or above the threshold, sending the second IP packet via the second RAT.

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21. The method of claim 1, wherein the first RAT is at least one of a WiFi RAT, an LTE RAT, a WCDMA/HSPA RAT, an UTRAN RAT, or an E-UTRAN RAT; and

wherein the second RAT is at least one of a WiFi RAT, an LTE RAT, a WCDMA/HSPA RAT, an UTRAN RAT, or an E-UTRAN RAT.

22. The method of claim 1, wherein the first RAT is a WiFi RAT operating over an industrial, scientific and medical (ISM) radio band and the second RAT is a WiFi RAT operating over a TV white space (TVWS) radio band.

23. A node in communication with a wireless communication system, the node comprising:

a processor in operable communication with a plurality of radio access technologies (RATs), the processor configured to:

receive first feedback information associated with a first RAT;

receive second feedback information associated with a second RAT;

determine a first IP packet to send via the first RAT according to the first and second feedback information;

determine a second IP packet to send via the second RAT according to the first and second feedback information, wherein the first and second IP packets are part of an Internet Protocol (IP) flow addressed to a receiving node;

send the first IP packet via the first RAT; and

send the second IP packet via the second RAT.

24. The node of claim 23, wherein the processor is further configured to:

establish a first communication path via the first RAT associated with the node; and

establish a second communication path via the second RAT associated with the node.

25. The node of claim 23, wherein the IP flow is associated with a single application.

26. The node of claim 23, wherein the node is an access point (AP) and the receiving node is a wireless transmit/receive unit (WTRU).

27. The node of claim 23, wherein the node is a WTRU and the receiving node is an AP.

28. The node of claim 23, wherein each of the first feedback information and the second feedback information comprise at least one of a medium access delay, a frame error rate, an average data rate, a received signal strength indication (RSSI), queuing latency per access category per RAT, end-to-end latency, a backoff time, a number of channels, channel bandwidth, a media access control (MAC) type, MAC aggregation support, an access category, a transmission opportunity (TXOP) duration, an estimated arrival rate of a packet, an average serving rate, an average serving latency, a second moment of average serving latency, an average vacation time, a second average of vacation time, or a transmission control protocol (TCP) parameter.

29. The node of claim 23, wherein the processor is configured to receive the first feedback information and the second feedback information via one or more of an A2 interface, an A3 interface, an A5a interface, and an A5b interface.

30. The node of claim 23, wherein the processor is further configured to determine to send the first IP packet via the first RAT and the second IP packet via the second RAT according to at least one rule, the at least one rule comprising a quality of service (QoS) class rule.

31. The node of claim 30, wherein the at least one rule further comprises at least one of a device capability rule, an operator policy rule, an IP packet flow rule, a device coordinate rule, a source domain rule, a source IP address rule, a destination domain rule, a destination IP address rule, IP protocol rule, a port number rule, a subscriber priority rule, a link quality rule, a charging rule, and a security rule.

32. The node of claim 23, wherein the processor is further configured to:

determine a time duration and a bandwidth requirement for the IP flow; and

request resources on the first RAT and on the second RAT based on the time duration and the bandwidth requirement for the first IP packet and the second IP packet, wherein the resources are characterized by the time duration and the bandwidth requirement.

33. The node of claim 32, wherein the processor is further configured to:

receive a quality of service (QoS) of the first IP packet and a QoS of the second IP packet, wherein the resources on the first RAT and on the second RAT are requested based

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further on at least one of the first feedback information, the second feedback information, the QoS of the first IP packet, and the QoS of the second IP packet.

34. The node of claim 32, wherein the processor is configured to receive the resources on the first RAT and on the second RAT using one or more of an A1 interface and an A2 interface.

35. The node of claim 23, wherein the processor is further configured to:

receive first maximum transmit unit (MTU) information associated with the first RAT;

receive second MTU information associated with the second RAT;

receive packet size information associated with the first IP packet;

receive packet size information associated with the second IP packet;

adjust at least one of a size of a MTU of the first IP packet or a size of a MTU of the second IP packet based on the first MTU information and the second MTU information.

36. The node of claim 35, wherein the size of the MTU of the first packet is different from the size of the MTU of the second packet.

37. The node of claim 35, wherein the size of the MTU of the first packet is the same as the size of the MTU of the second packet.

38. The node of claim 23, wherein the receiving node a multi-RAT node, and the processor is further configured to:

receive a signal from the multi-RAT node, the signal being characterized by a plurality of available RATs of the multi-RAT node.

39. The node of claim 23, wherein the processor is further configured to determine to send the first IP packet via the first RAT and the second IP packet via the second RAT according to a packet distribution mode.

40. The node of claim 39, wherein the packet distribution mode is at least one of diversity mode, multiplexing mode, hybrid mode, or dynamic RAT selection mode.

41. The node of claim 23, wherein the processor is further configured to:

determine whether channel quality of the first RAT is below a threshold;

upon determining that channel quality of the first RAT is below the threshold, duplicate the first IP packet to create a first instance of the first IP packet and a second instance of the first IP packet;

send the first instance of the first IP packet via the first RAT; and

send the second instance of the first IP packet via a third RAT.

42. The node of claim 41, wherein the processor is further configured to:

determine whether channel quality of the second RAT is below the threshold; and

upon determining that channel quality of the second RAT is at or above the threshold, send the second IP packet via the second RAT.

43. The node of claim 23, wherein the first RAT is at least one of a WiFi RAT, an LTE RAT, a WCDMA/HSPA RAT, an UTRAN RAT, or an E-UTRAN RAT; and

wherein the second RAT is at least one of a WiFi RAT, an LTE RAT, a WCDMA/HSPA RAT, an UTRAN RAT, or an E-UTRAN RAT.

44. The node of claim 23, wherein the first RAT is a WiFi RAT operating over an industrial, scientific and medical (ISM) radio band and the second RAT is a WiFi RAT operating over a TV white space (TVWS) radio band.

45. A method of aggregating bandwidth available on multiple radio access technologies (RATs), the method comprising:

assigning a first variable to a first RAT and a second variable to a second RAT;

incrementing the first variable of the first RAT by a first rate, the first rate related to an estimated arrival rate of a packet transmitted across the first RAT;

incrementing the second variable of the second RAT by a second rate, the second rate related to an estimated arrival rate of a packet transmitted across the second RAT;

determining whether the first variable is greater than or equal to a threshold value;

upon determining that the first variable is greater than or equal to the threshold value and that the second variable is less than the threshold value, sending a packet across the first RAT; and

decreasing the first variable by the threshold value.

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46. A method of aggregating bandwidth available on multiple radio access technologies (RATs), the method comprising:

assigning a variable to each of a plurality of RATs;

incrementing each of the plurality of variables at a rate, the rate related to an estimated arrival rate of a packet transmitted across the RAT to which the variable is assigned;

determining whether a variable of the plurality of variables is greater than or equal to a threshold value;

upon determining that the variable of the plurality of variables is greater than or equal to the threshold value, sending a packet across the RAT whose variable is greater than or equal to the threshold value; and

decreasing the variable that is greater than or equal to the threshold value by a number.

47. A method for aggregating IP packets into an IP flow, the method comprising:

receiving a first IP packet via a first radio access technologies (RAT);

receiving a second IP packet via a second RAT, wherein the first RAT is associated with a first license exempt (LE) band channel, and the second RAT is associated with a second LE band channel, wherein the first IP packet and the second IP packet are part of the IP flow; and

aggregating the first IP packet and second IP packet to recreate the IP flow.

48. The method of claim 47, further comprising:

receiving a third IP packet via a third RAT, wherein the third RAT is associated with a WiFi channel; and

aggregating the first IP packet, the second IP packet, and the third IP packet to recreate the IP flow.

49. The method of claim 47, wherein the first IP packet comprises a first header and the second IP packet comprises a second header, the first header and the second header relating to an order of IP packets of the IP flow.

50. The method of claim 49, further comprising:

reading the first header of the first IP packet;

reading the second header of the second IP packet; and

aggregating the first IP packet and the second IP packet to recreate the IP flow based on the first header and the second header.

51. A node comprising an opportunistic multiple radio access technologies (RAT) aggregation (OMMA) layer, the OMMA layer comprising:

a controller in operable communication with a first radio access technology (RAT) and a second RAT, the controller configured to:

determine a first time duration and a first bandwidth requirement for a first IP packet;

determine a second time duration and a second bandwidth requirement for a second IP packet, wherein the first IP packet and the second IP packet are part of an IP flow addressed to a receiving node;

request resources on the first RAT and the second RAT based on the first time duration and the first bandwidth requirement for the first IP packet and based on the second time duration and second bandwidth requirement for the second IP packet; and

send instructions to a scheduler;

the scheduler in operable communication with the first RAT and the second RAT, the scheduler configured to:

receive first feedback information associated with the first RAT;

receive second feedback information associated with the second RAT;

determine to send the first IP packet via the first RAT according to the first and second feedback information and the instructions; and

determine to send the second IP packet via the second RAT according to the first and second feedback information and the instructions.

52. The node of claim 51, wherein the IP flow is associated with a single application.

53. The node of claim 51, wherein the node is an access point (AP) and the receiving node is a wireless transmit/receive unit (WTRU).

54. The node of claim 51, wherein the node is a WTRU and the receiving node is an AP.

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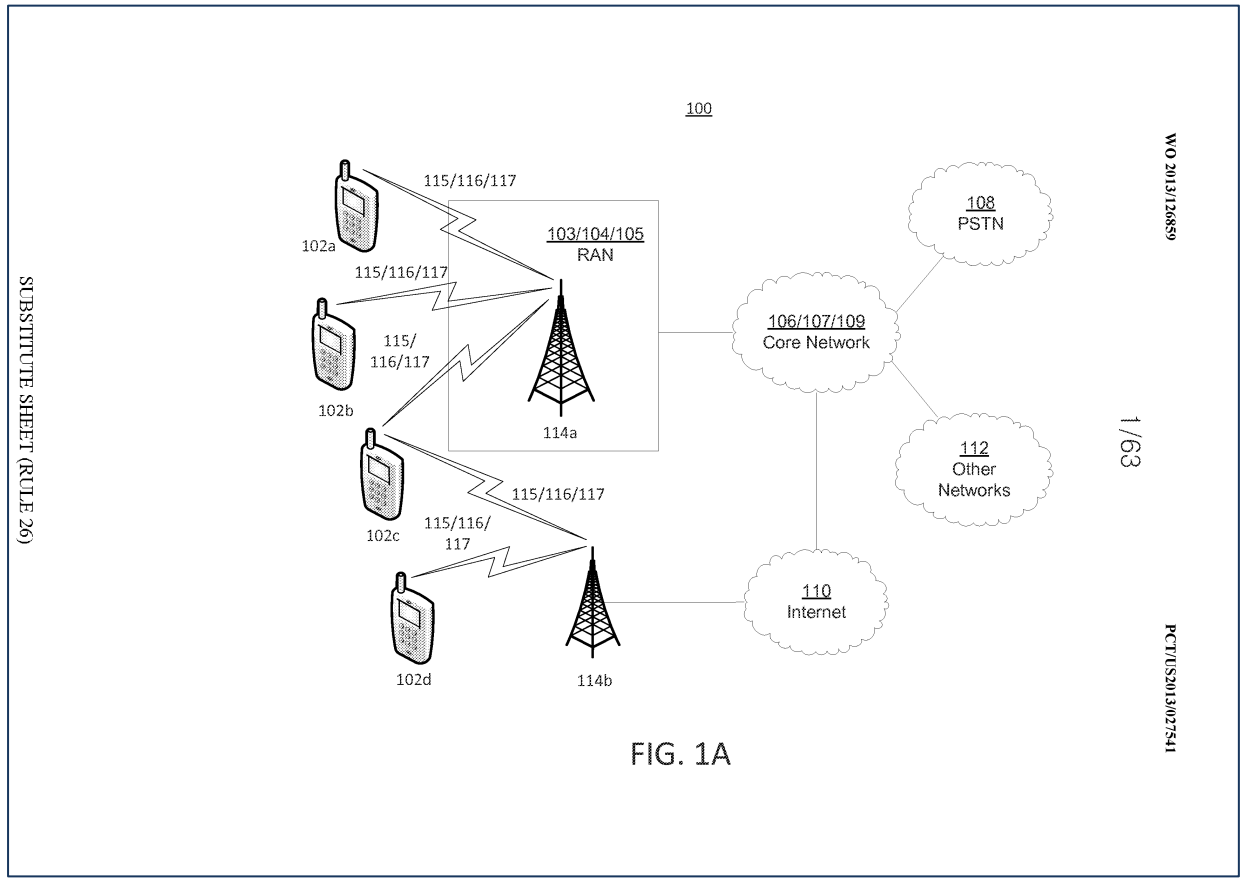


FIG. 1A

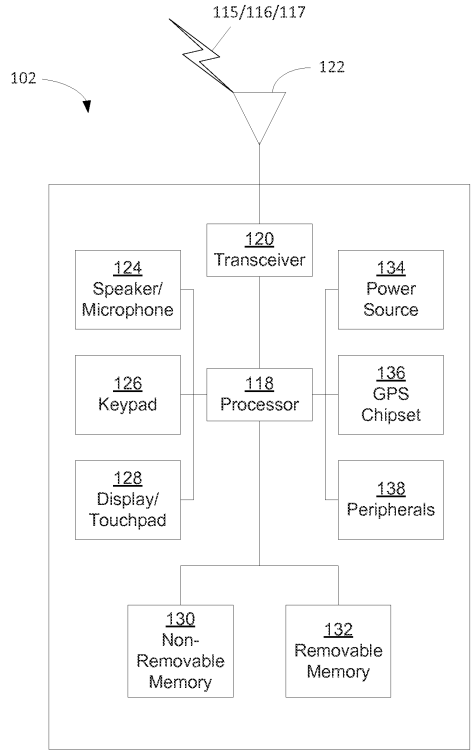


FIG. 1B

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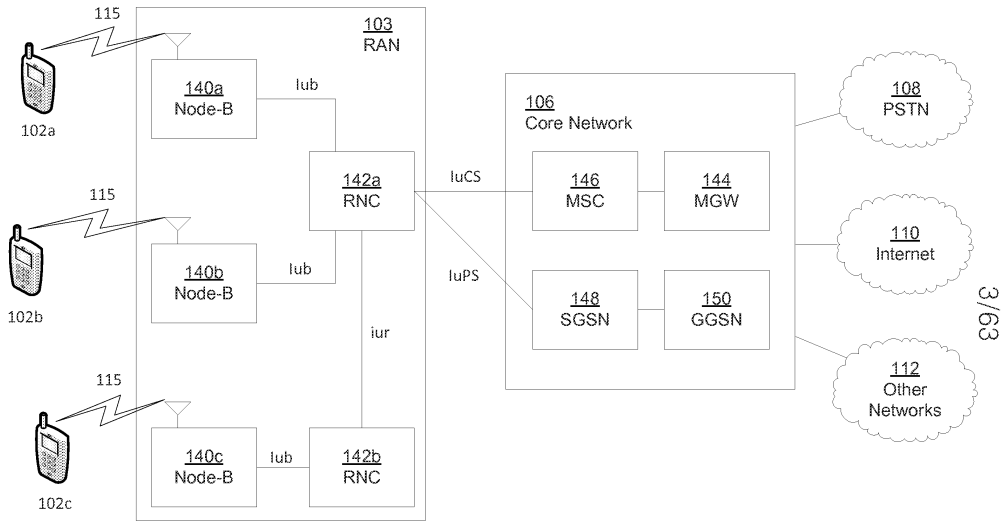


FIG. 1C

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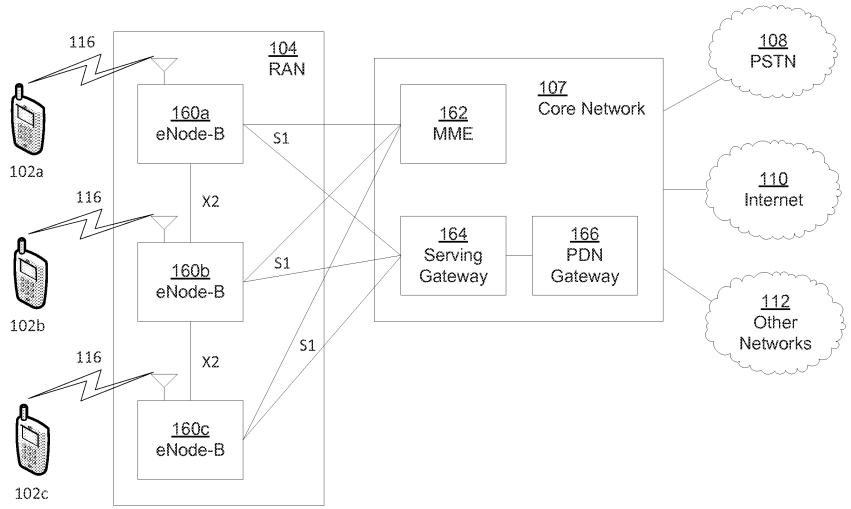


FIG. 1D

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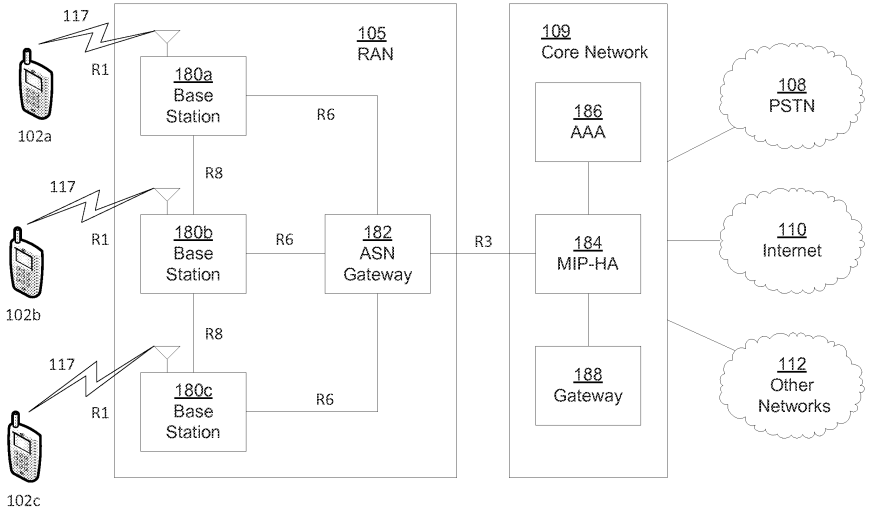


FIG. 1E

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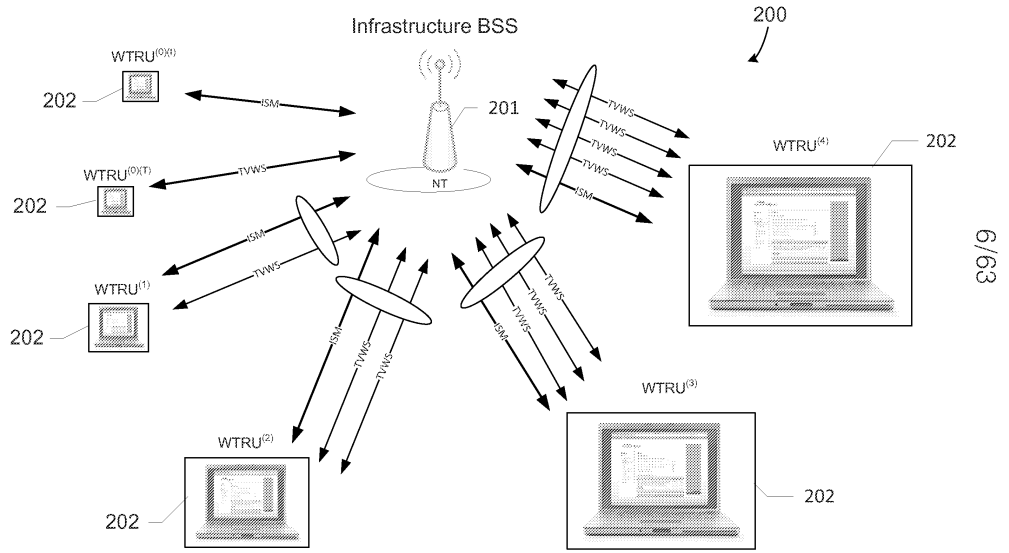


FIG. 2

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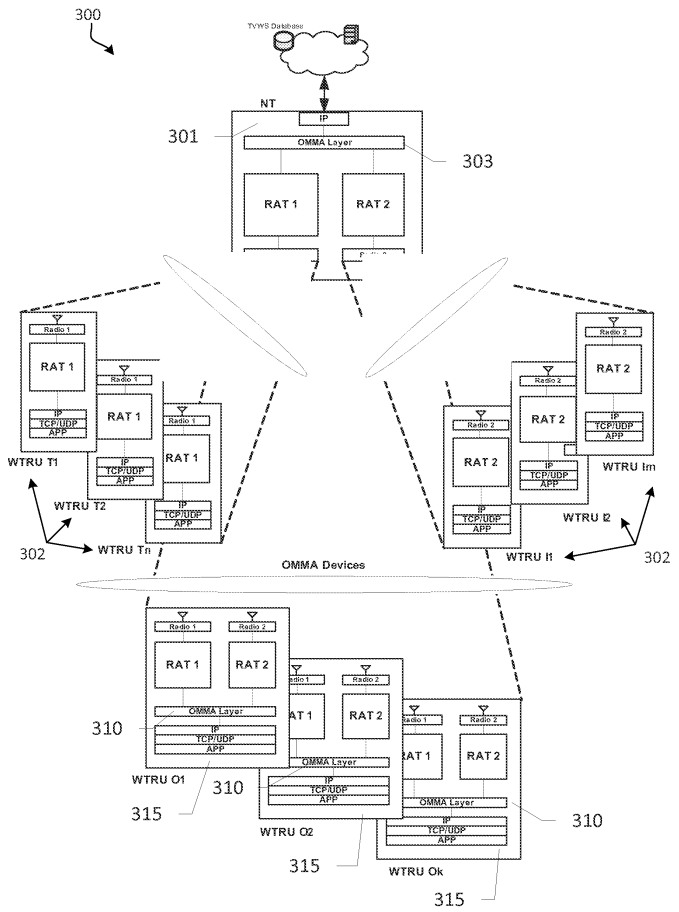


FIG. 3

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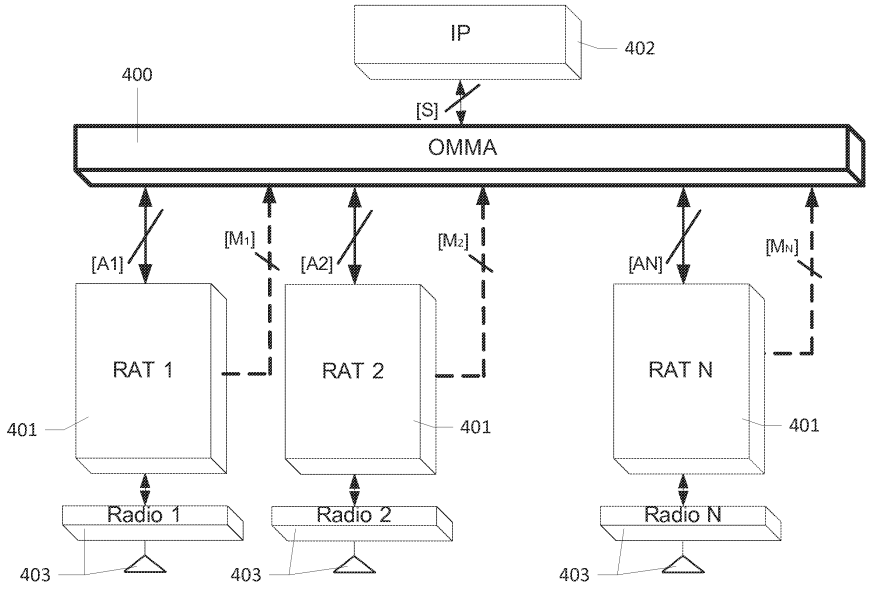


FIG. 4

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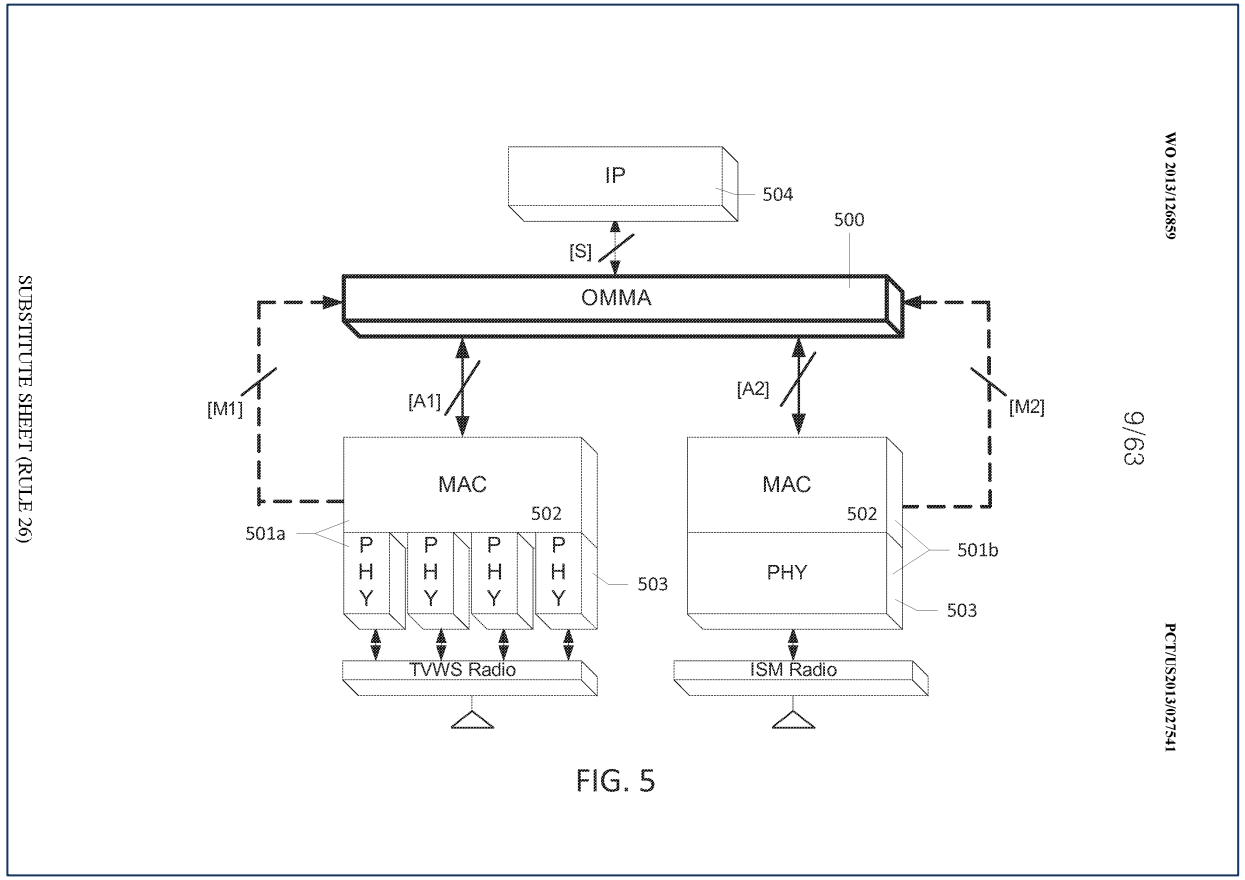


FIG. 5

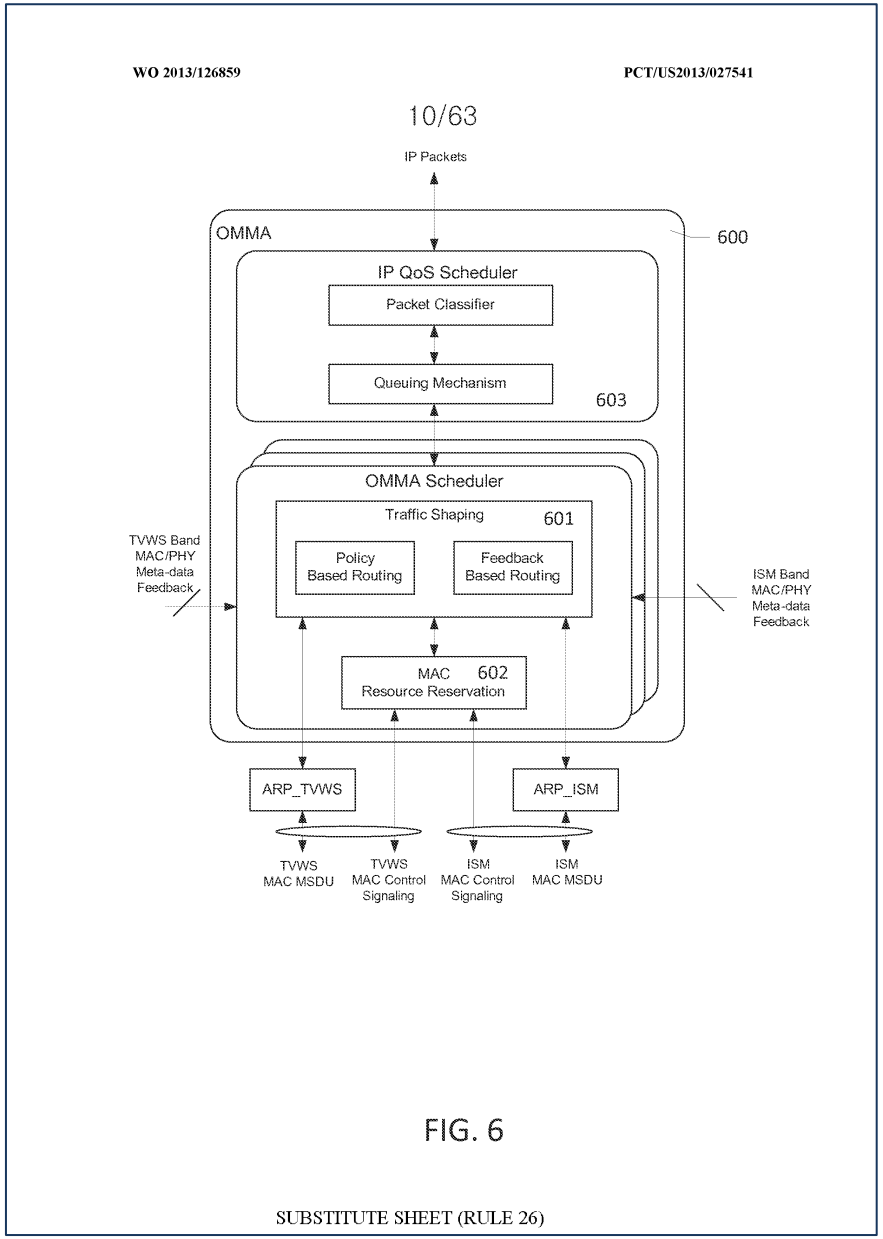


FIG. 6

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Parameter	Value	Comment
Number of RATs	N	'N' is an integer with a minimum value of 1
RAT Types	[R1, R2, ..., RP]	Vector of integers where 'P' is the number of possible RAT types and is an integer with a minimum value of 1; Rx is the identity of the RAT
Spectral Band per RAT Type	[Fmin, Fmax]	Fmin is the minimum frequency of the band, and, Fmax is the maximum frequency of the band
	[Fc, B]	Fc is the center frequency of the band, and, B is the bandwidth
	K	'K' is a pre-defined identity of the channel as specified by the regulator, or, system administrator, etc.
MAC carrier aggregation per RAT Type	'0' or '1'	'0' implies MAC carrier aggregation is not enabled for the particular RAT Type; '1' implies MAC carrier aggregation is enabled for the particular RAT Type
MAC Feedback per RAT Type	'0' or '1'	'0' implies MAC feedback is not available for the particular RAT Type; '1' implies MAC feedback is available for the particular RAT Type
Metrics per RAT type	[M1, M2, ..., Mq]	Vector of integers where 'q' is the number of possible metrics per RAT types and is an integer with a minimum value of 1; Mx is the identity of the metric
OMMA Type	'Transparent' or 'Non-Transparent'	'Transparent' type implies that OMMA at the transmitter distributes packets per IP flow across RATs without any additional headers; 'Non-Transparent' type implies that OMMA at the transmitter distributes packets per IP flow across RATs with additional headers
OMMA Scheme	'Policy-Based', 'Feedback-Based, or, 'Hybrid'	'Policy-Based' scheme implies that OMMA at the transmitter distributes packets per IP flow across RATs based on pre-defined ratio; 'Feedback-Based' scheme implies that OMMA at the transmitter distributes packets per IP flow across RATs based on feedback from lower layers i.e. MAC/PHY 'Hybrid' scheme implies that OMMA at the transmitter distributes packets across some RATs based on 'Policy-Based' mode and across other RATs based on 'Feedback-Based' mode
OMMA Packet Dsitribution Modes	'Diversity', 'Multiplexing',	'Diversity' mode implies that OMMA at the transmitter duplicates IP packets across RATs;

FIG. 7

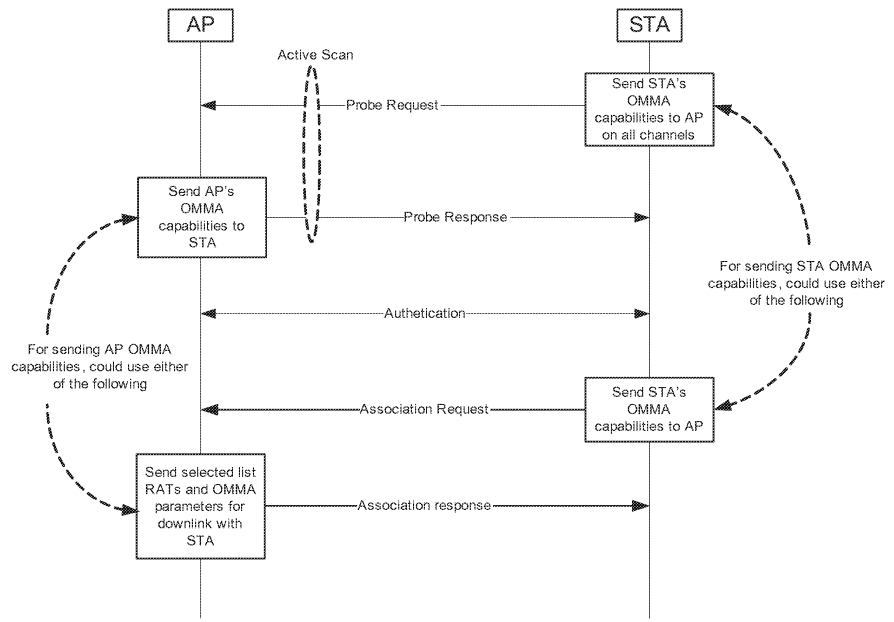


FIG. 8

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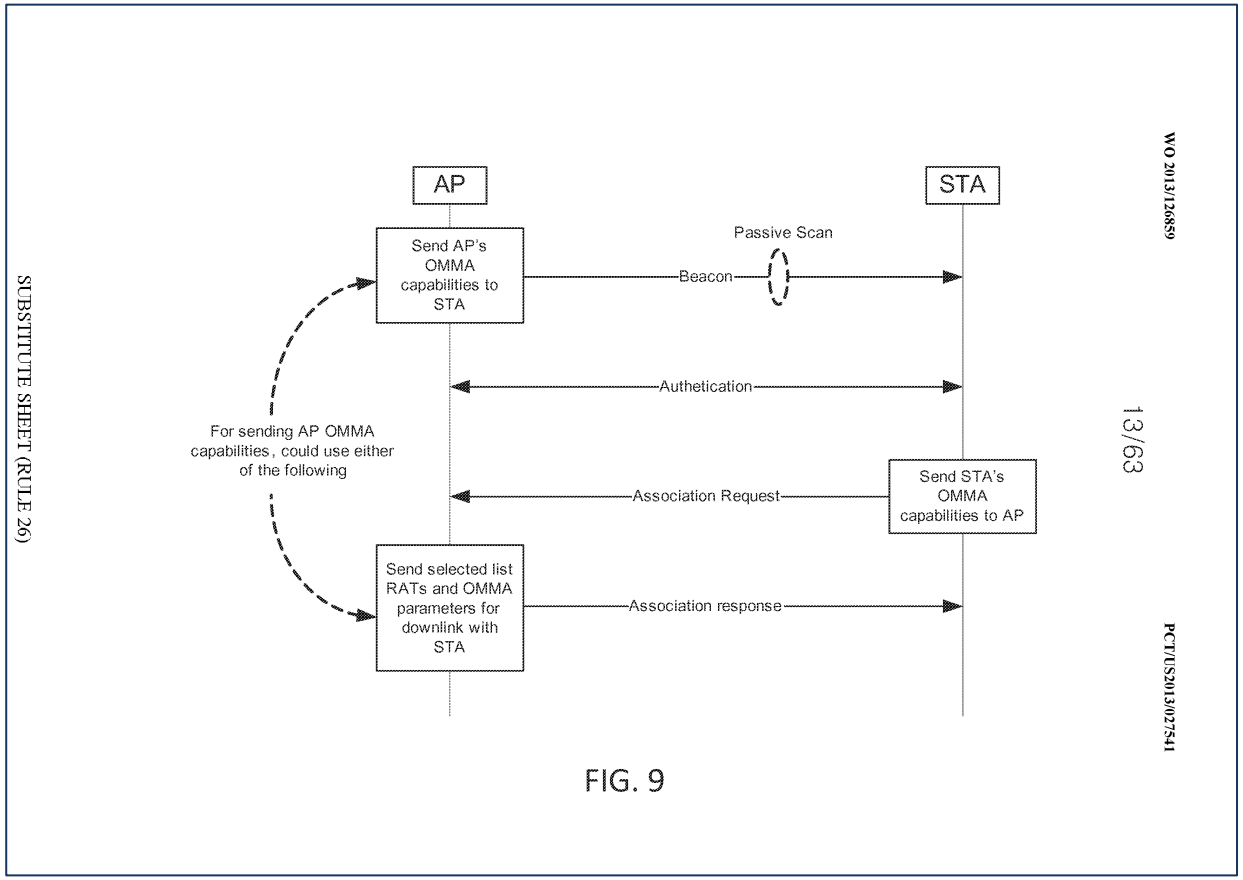


FIG. 9

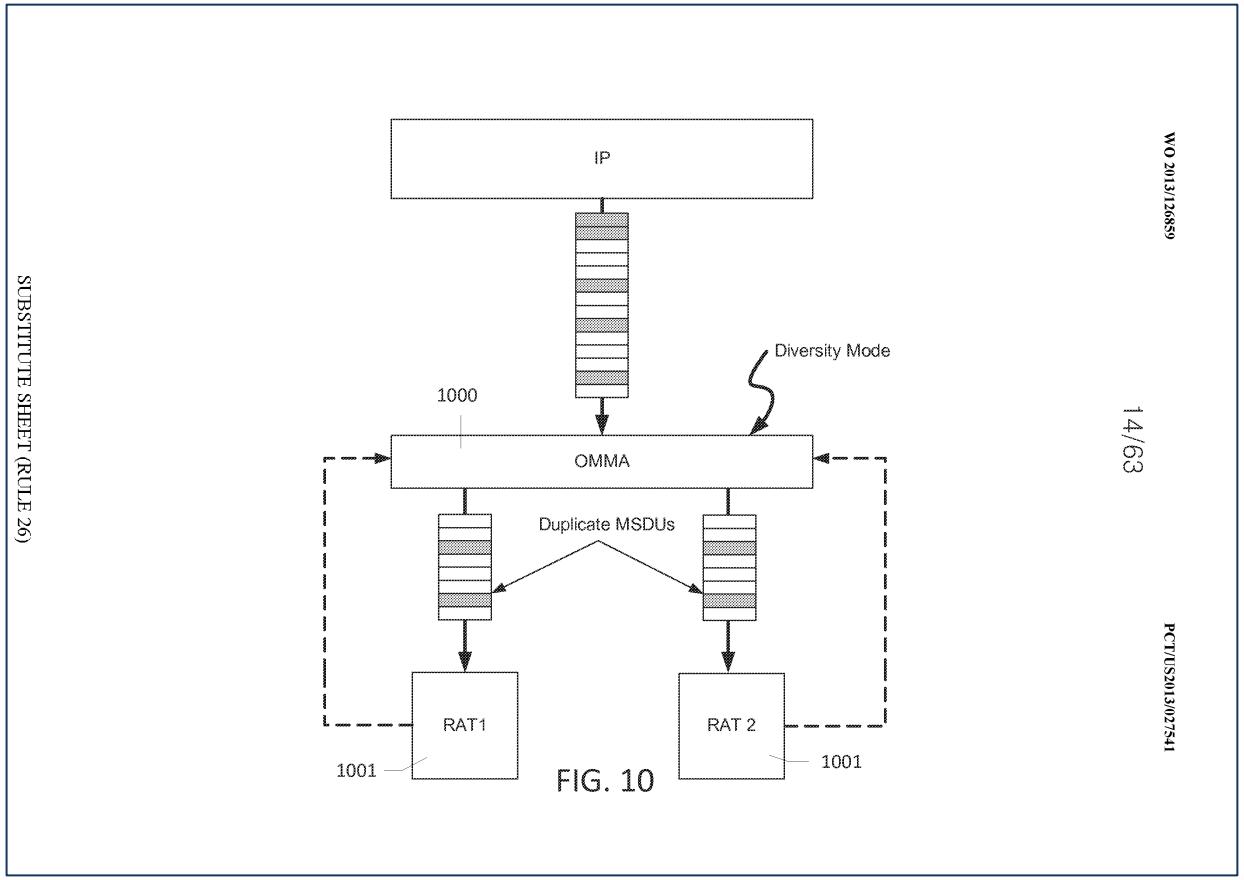
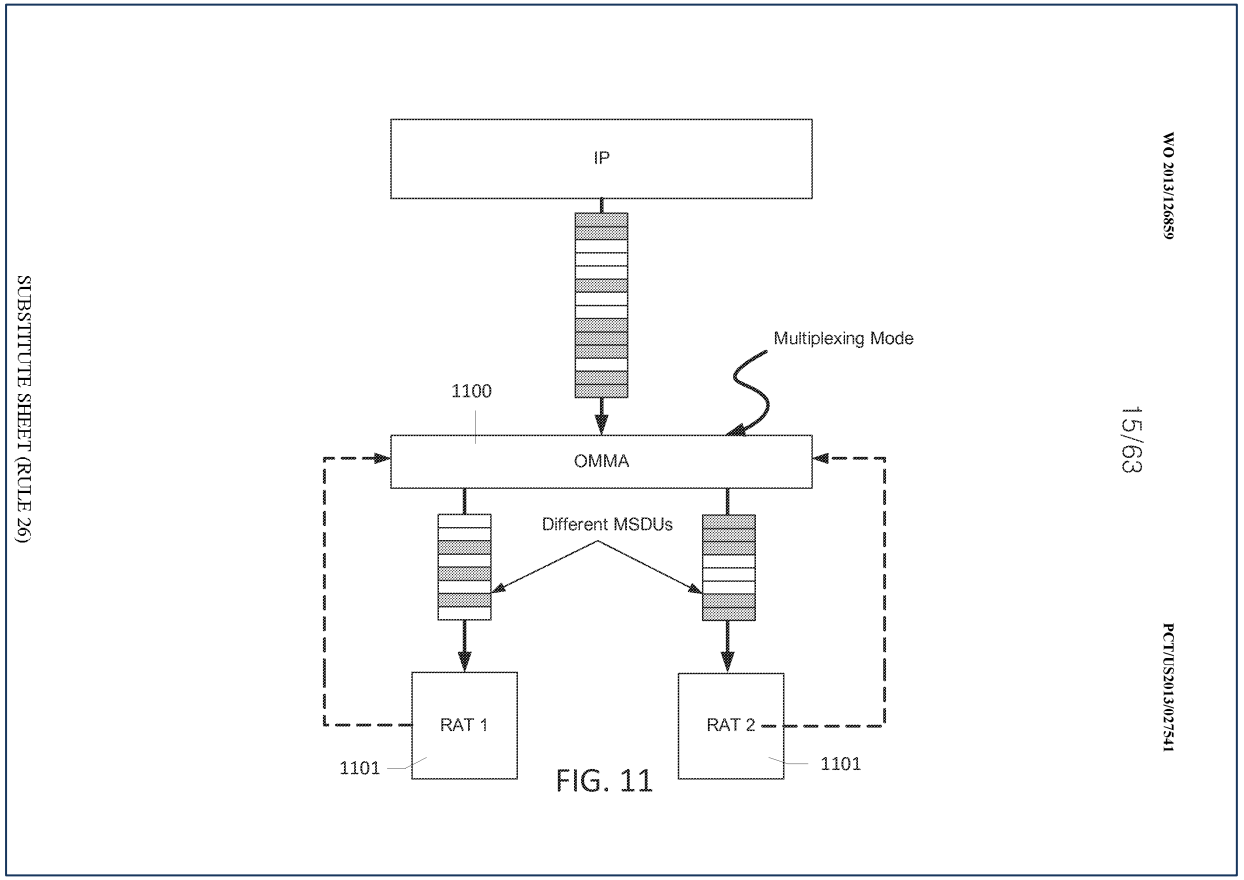
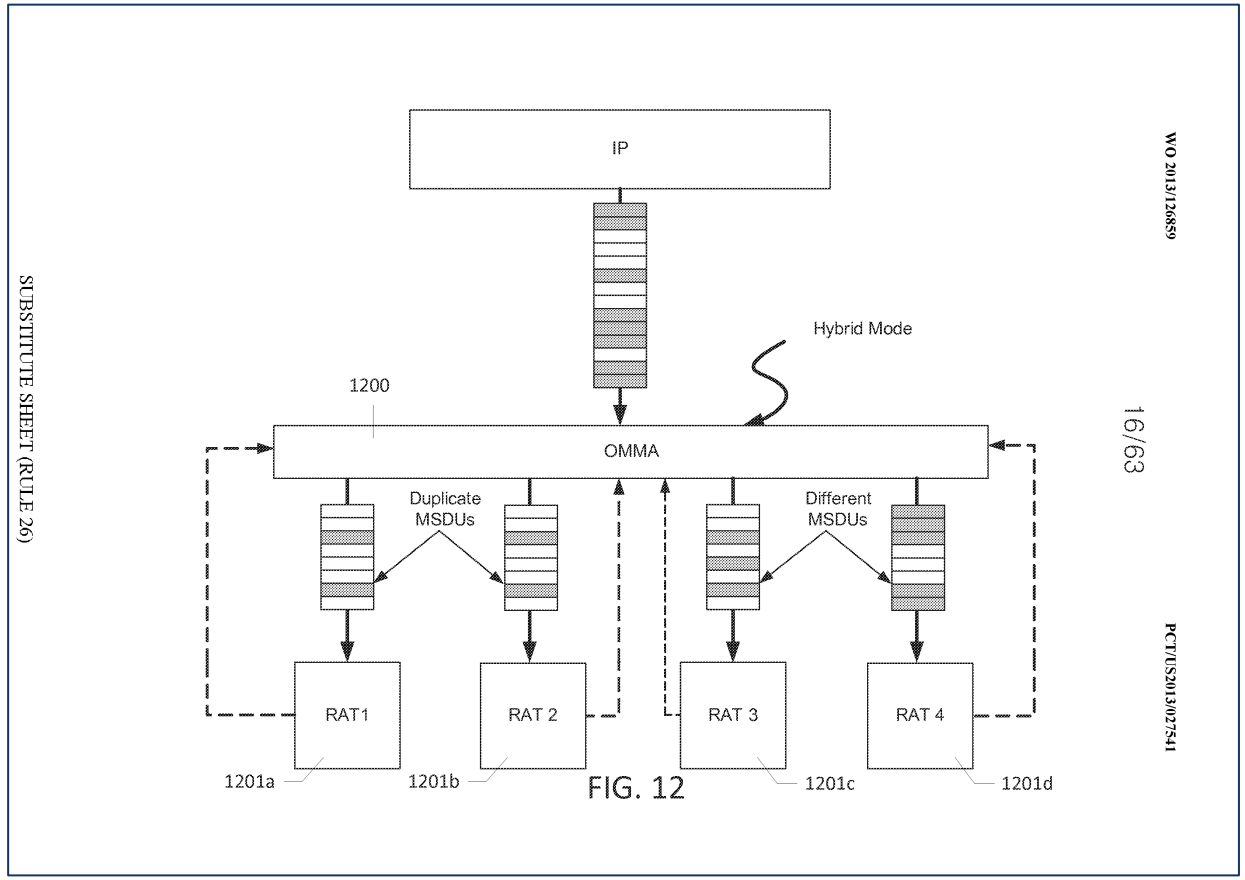


FIG. 10

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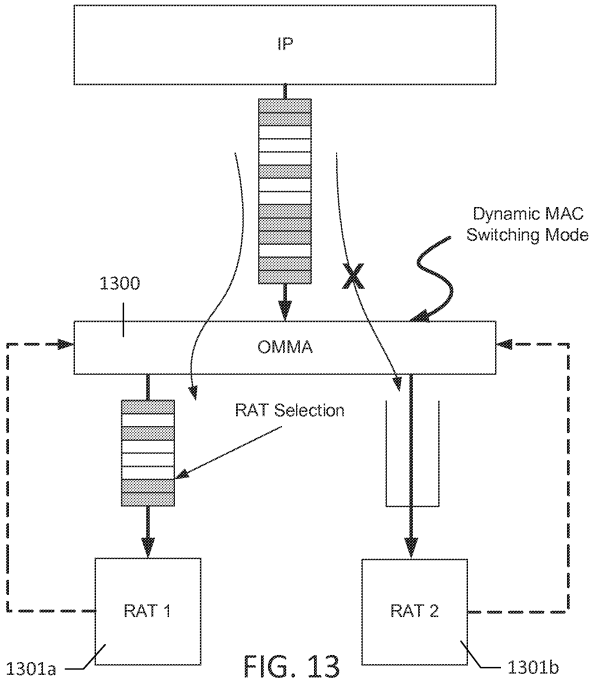


FIG. 13

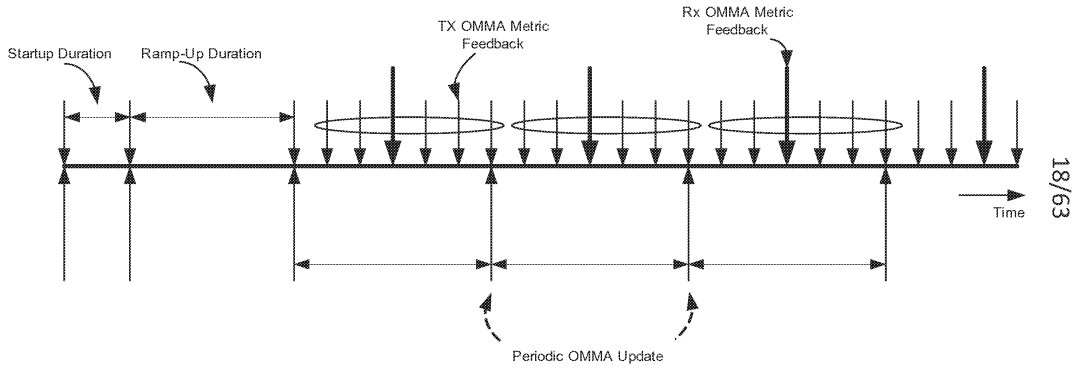


FIG. 14

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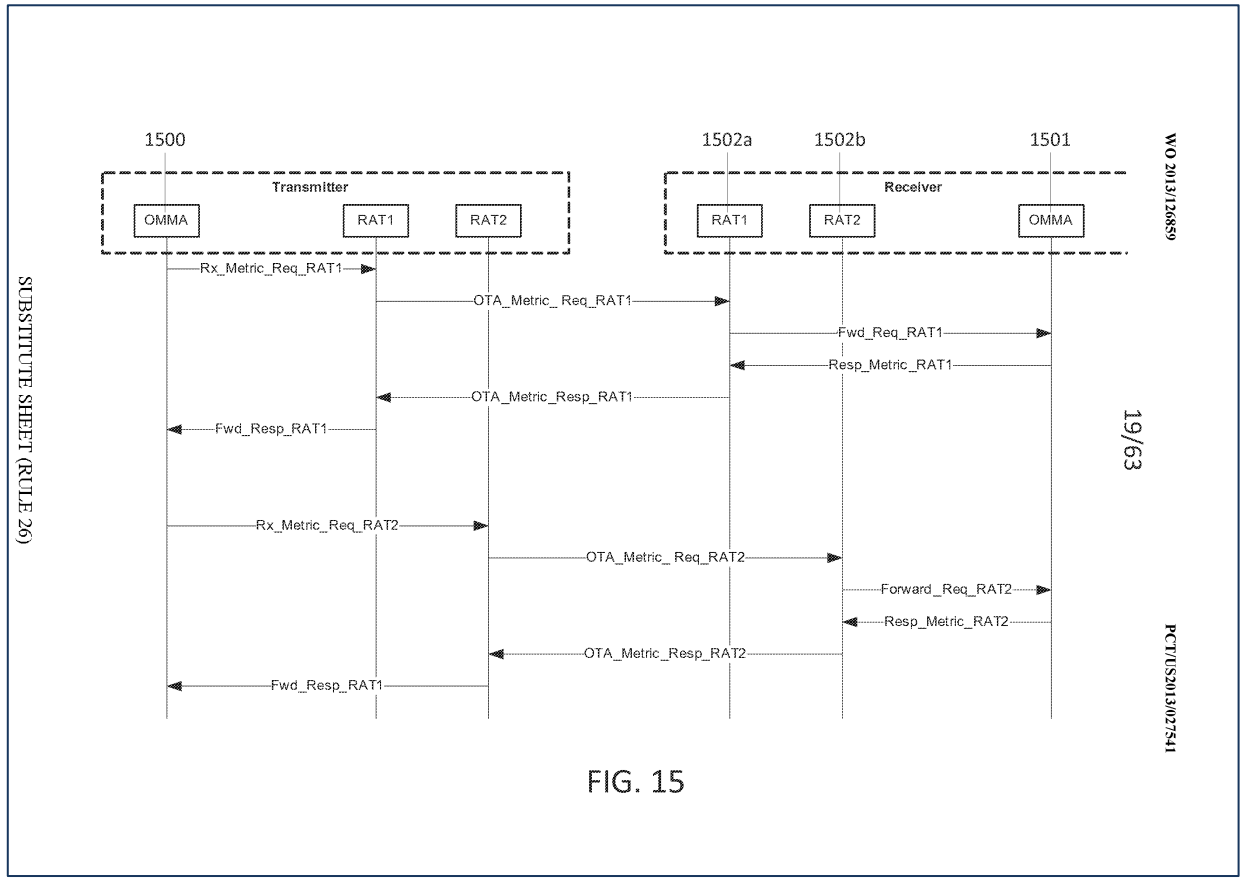


FIG. 15

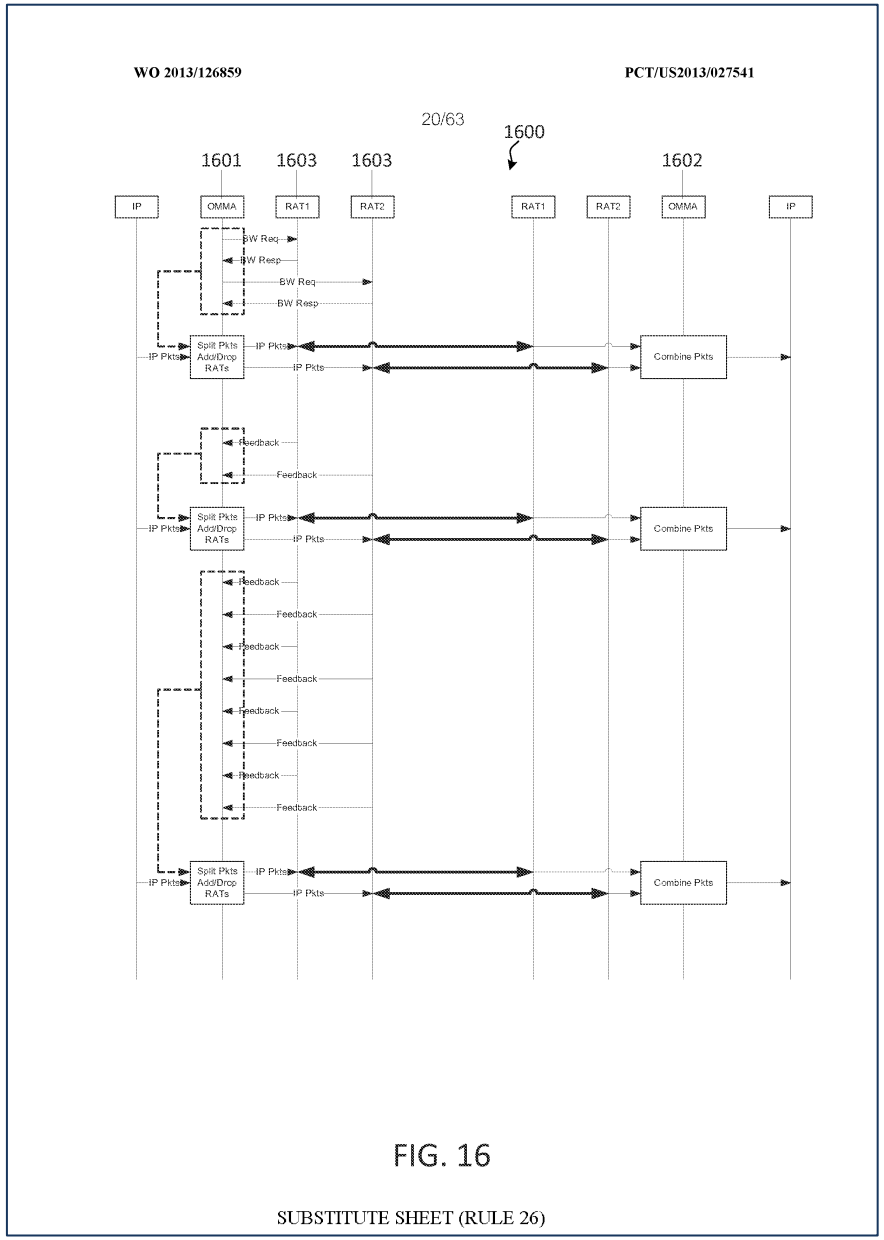


FIG. 16

SUBSTITUTE SHEET (RULE 26)

Appendix: Chincholi

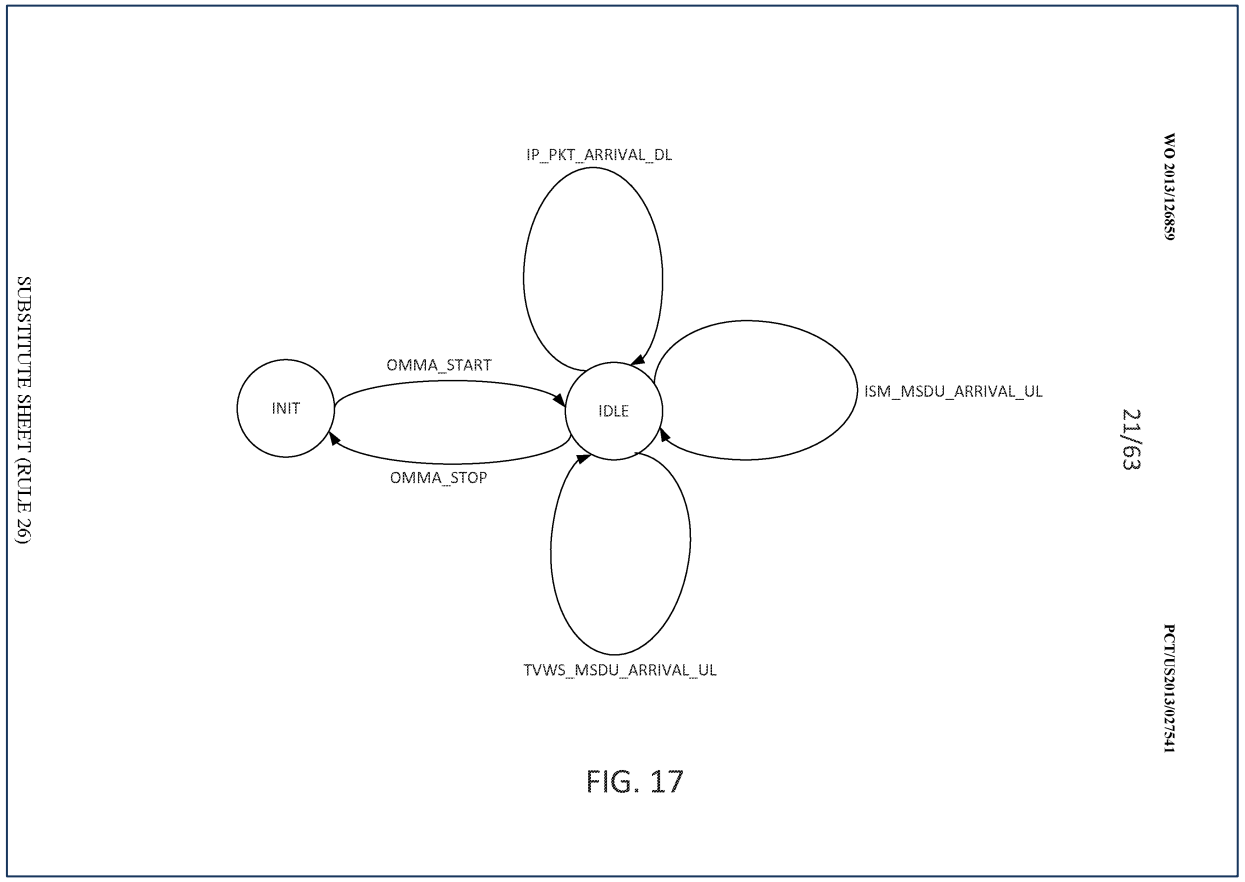


FIG. 17

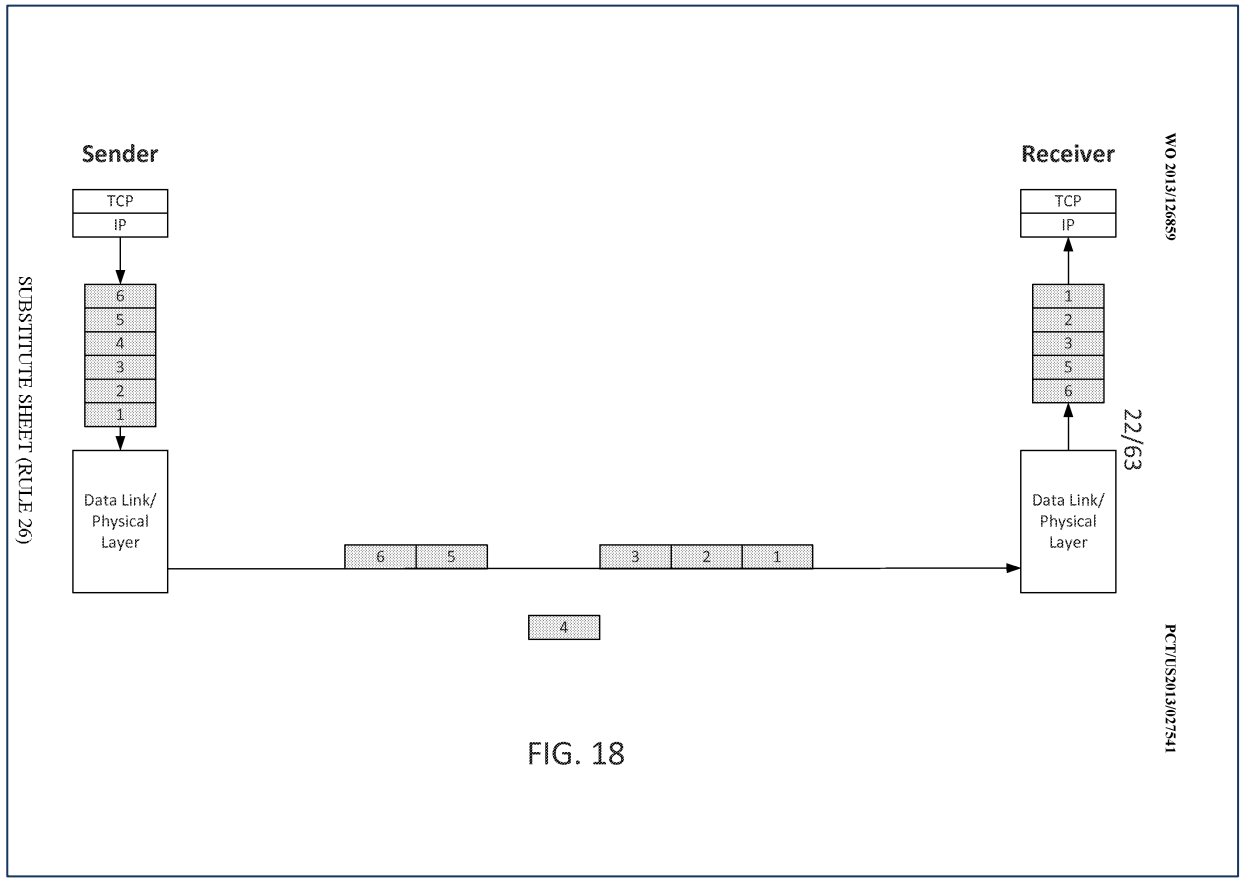


FIG. 18

Appendix: Chincholi

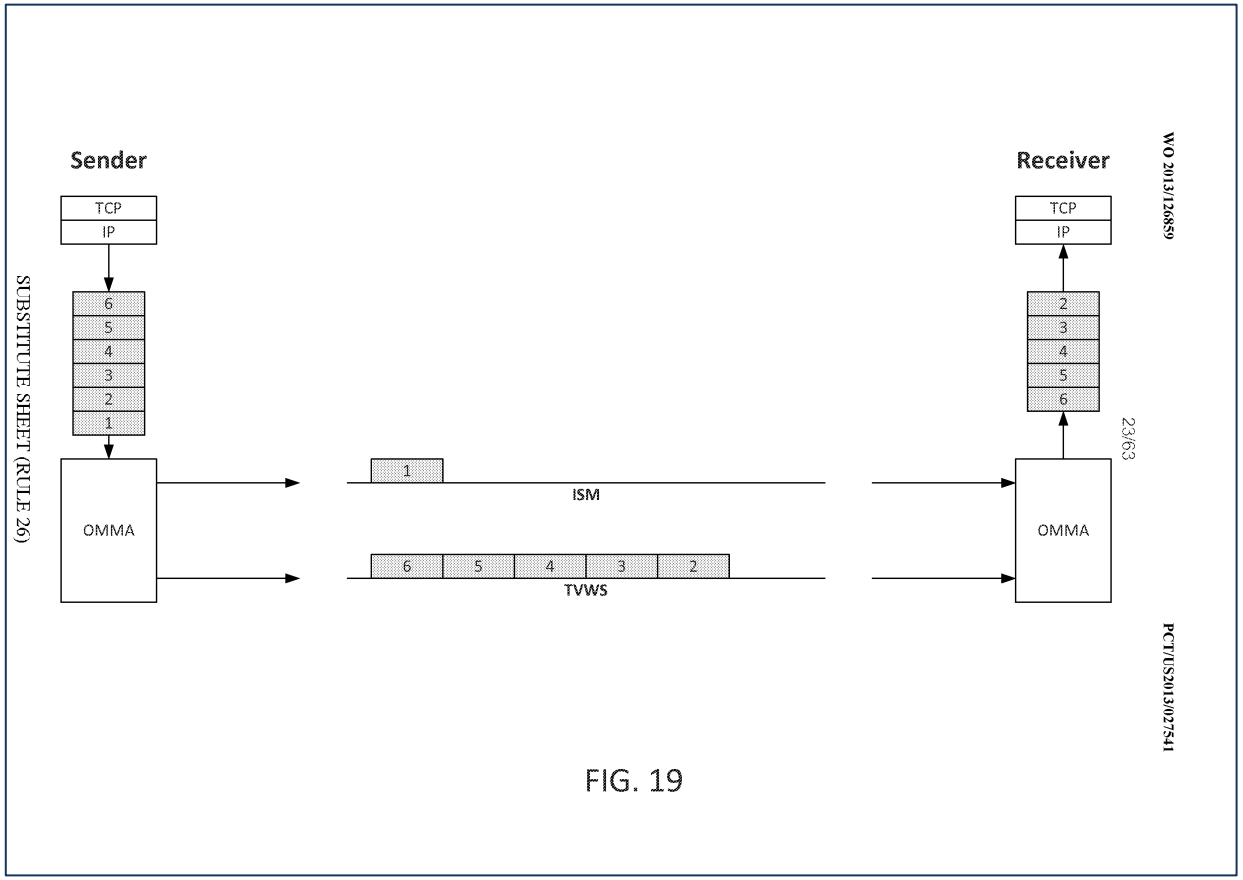


FIG. 19

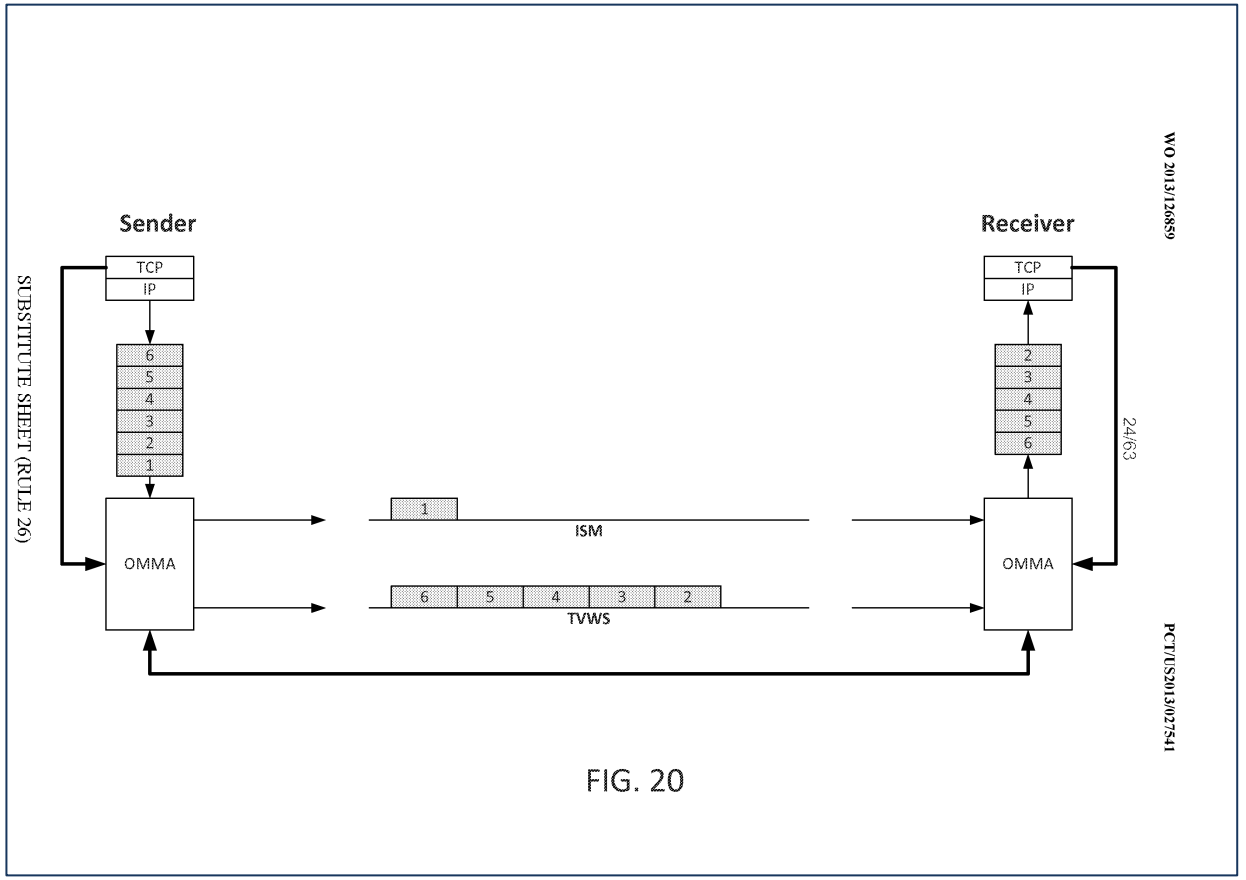


FIG. 20

Appendix: Chincholi

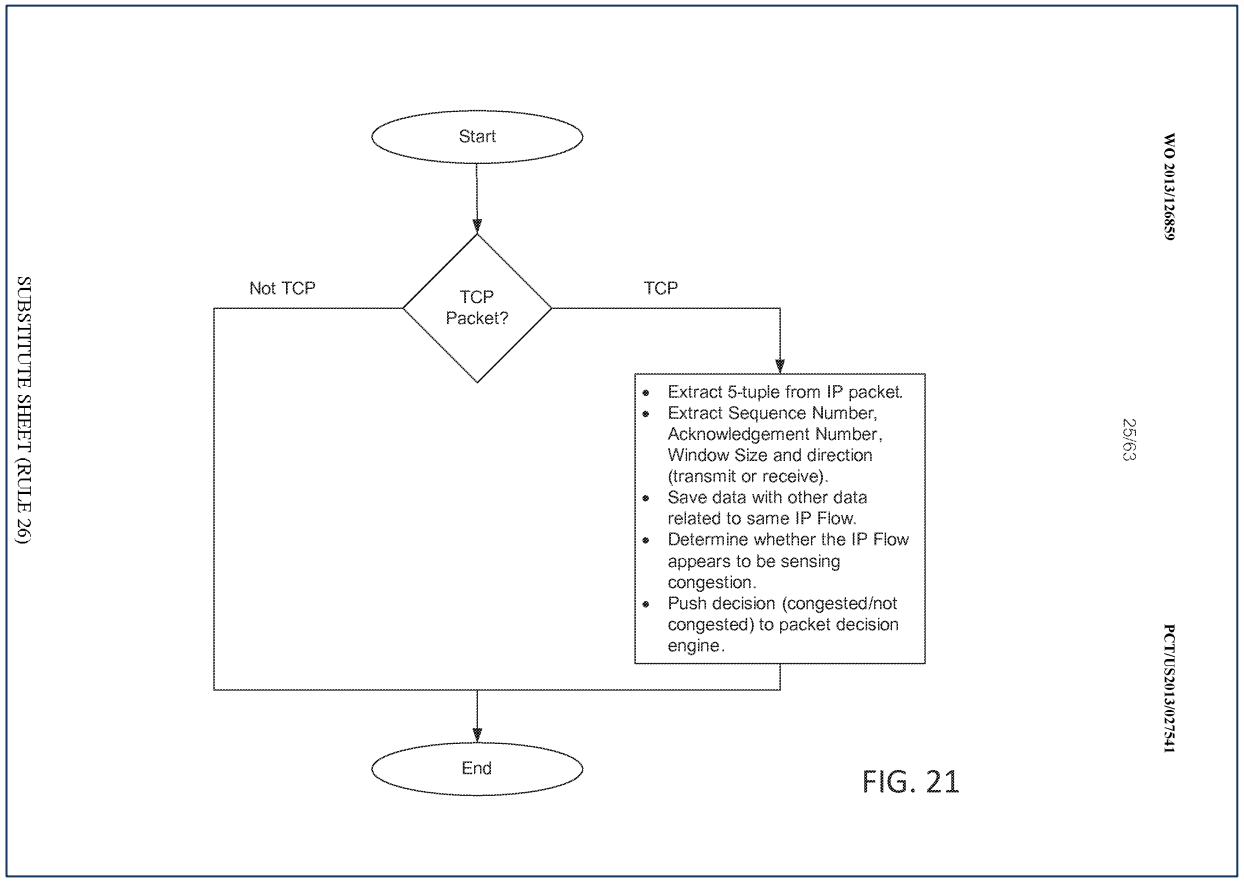


FIG. 21

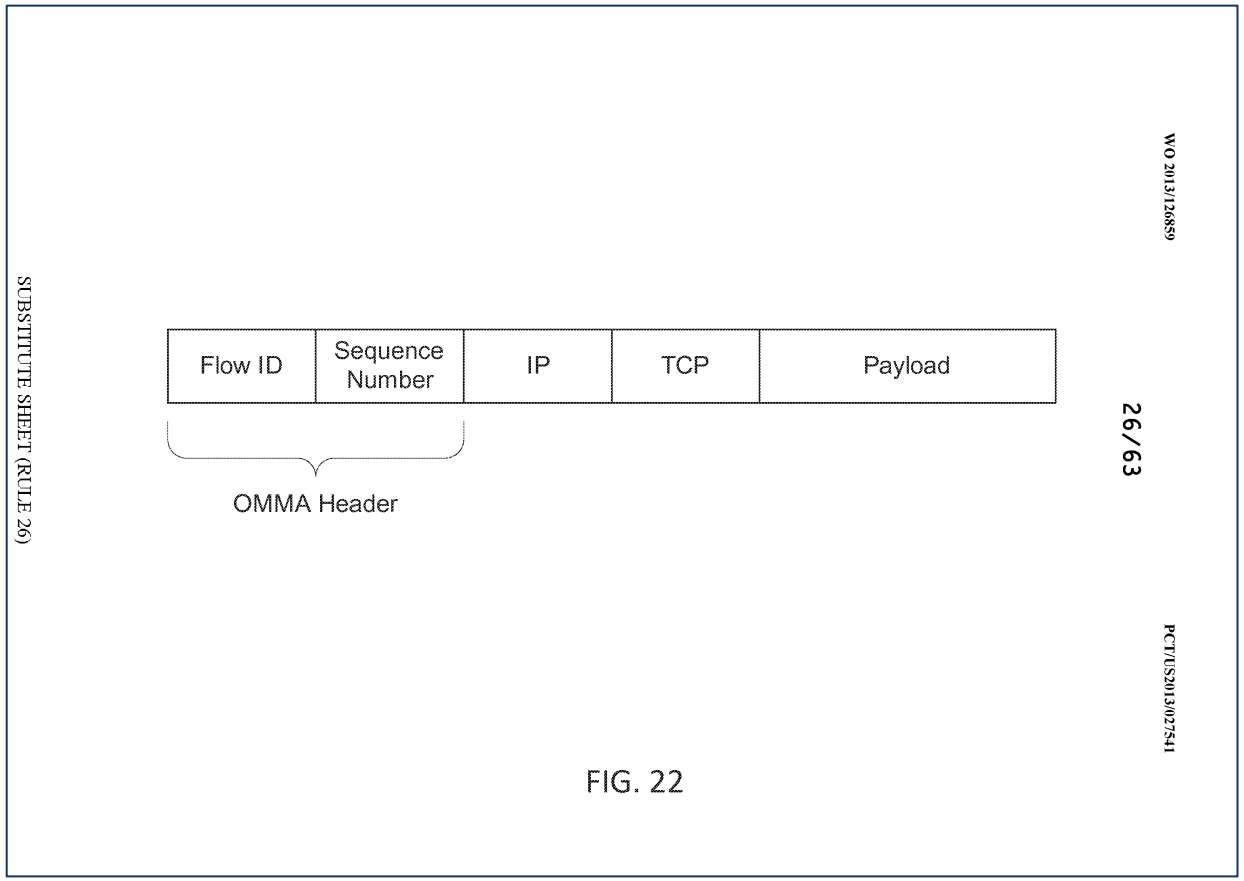


FIG. 22

Appendix: Chincholi

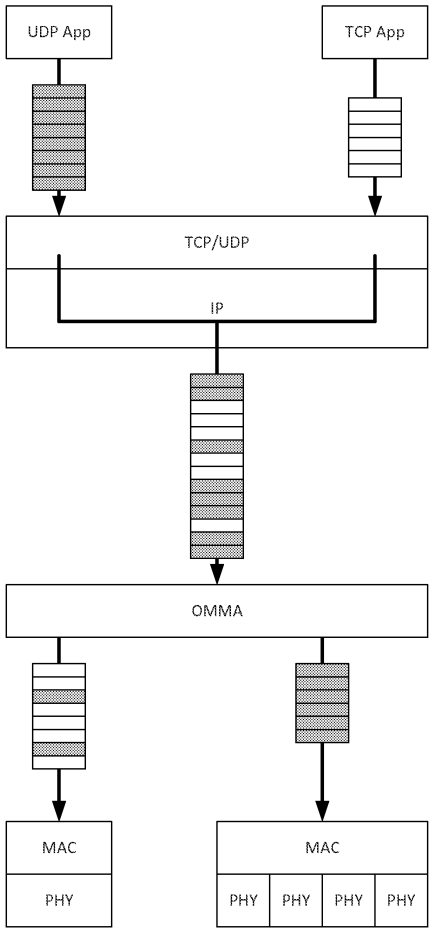


FIG. 23

Table maintained by an OMMA layer

5-tuple	Current Transport	Evaluation Period	Split	Mode

FIG. 24

Appendix: Chincholi

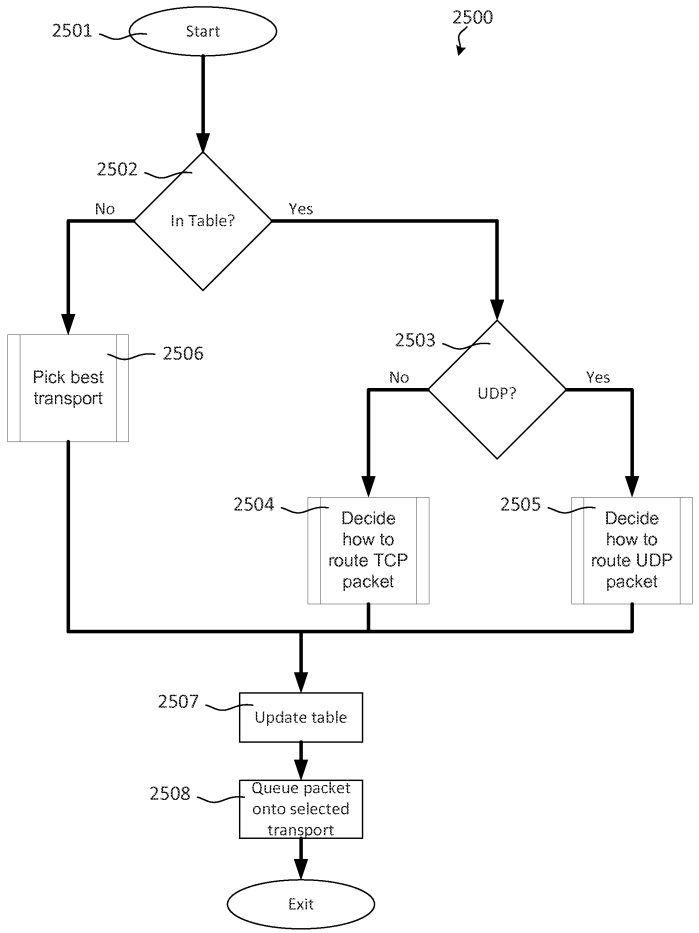


FIG. 25

SUBSTITUTE SHEET (RULE 26)

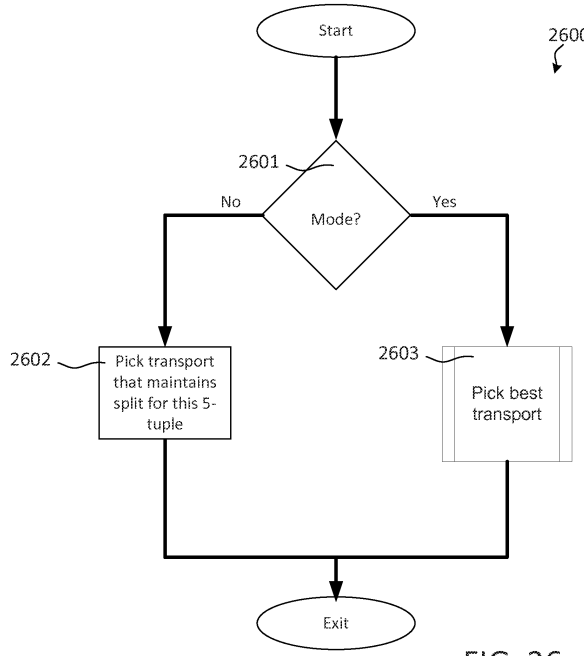


FIG. 26

Appendix: Chincholi

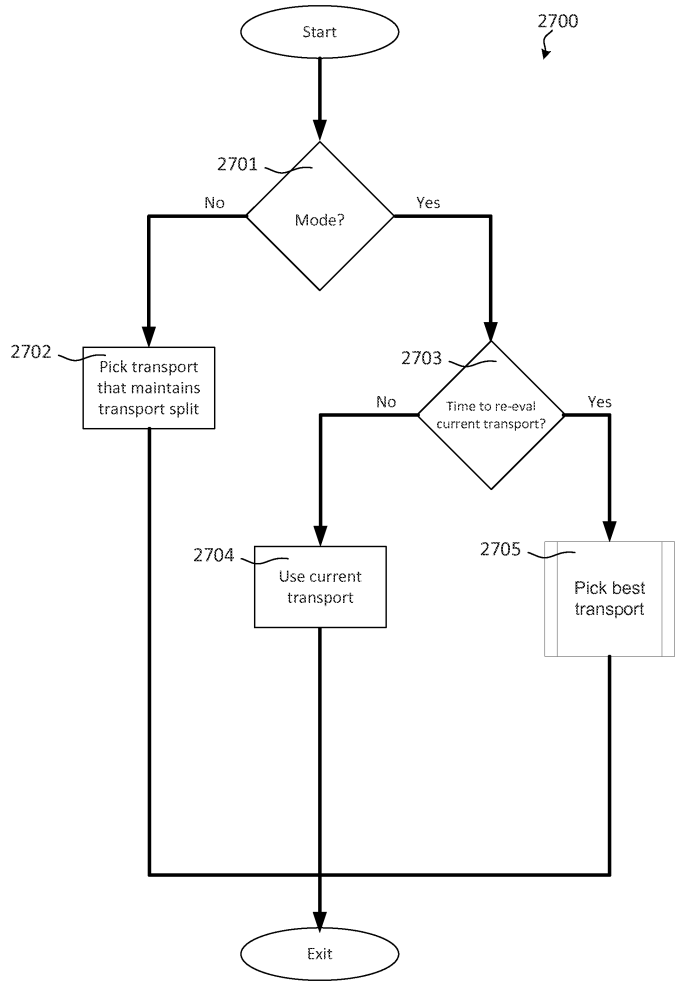


FIG. 27

SUBSTITUTE SHEET (RULE 26)

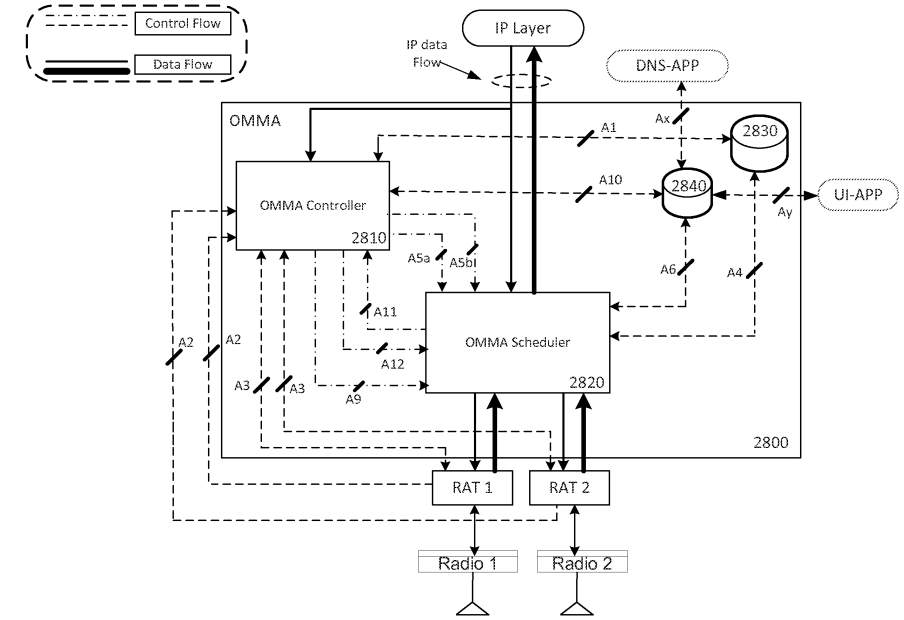


FIG. 28

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Appendix: Chincholi

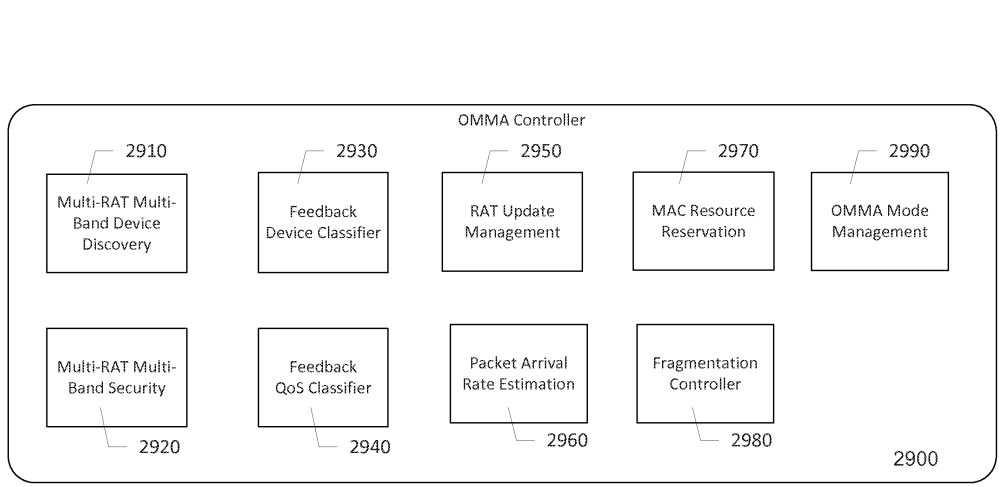


FIG. 29

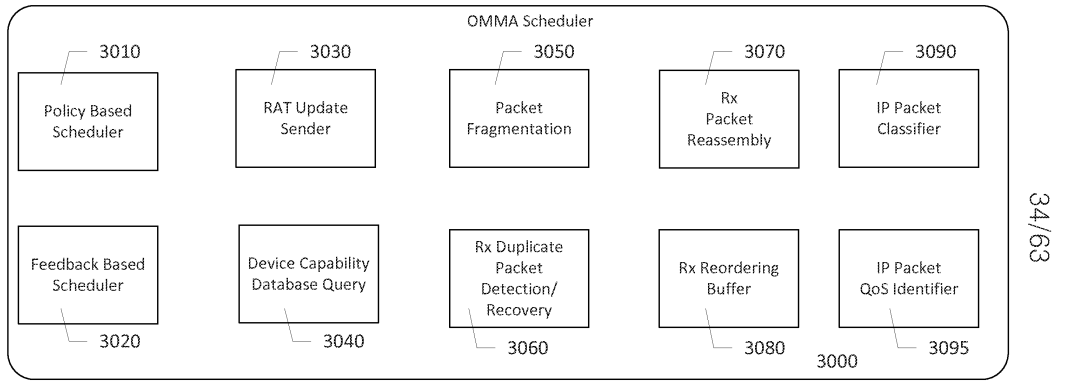


FIG. 30

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Appendix: Chincholi

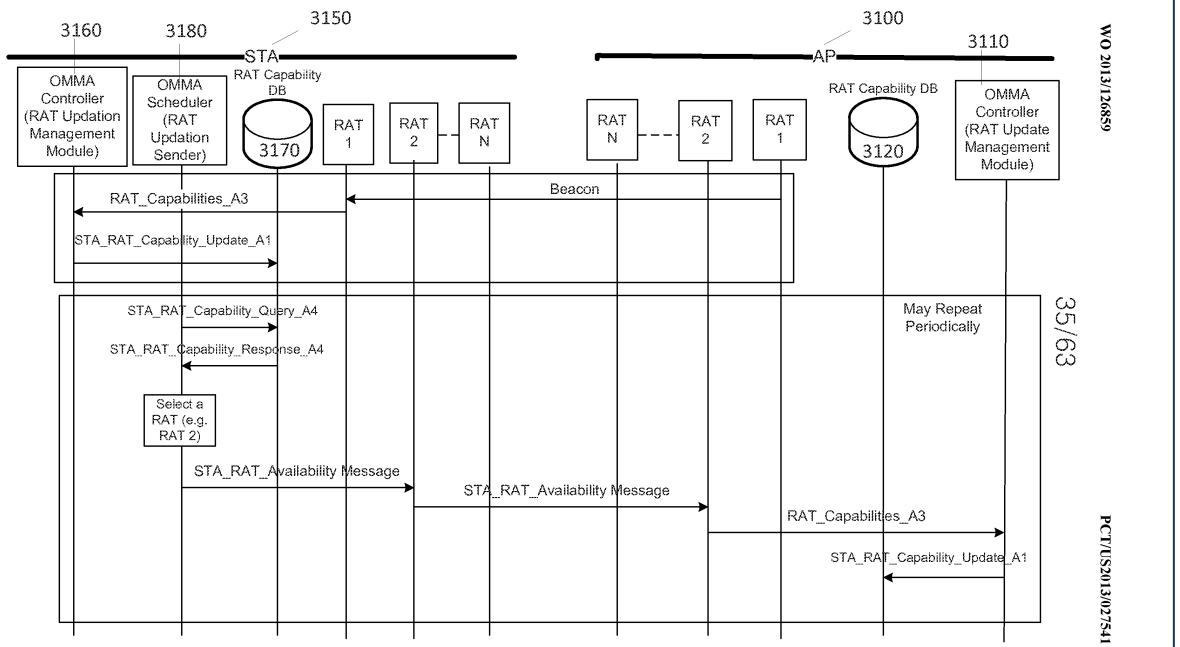


FIG. 31

SUBSTITUTE SHEET (RULE 26)

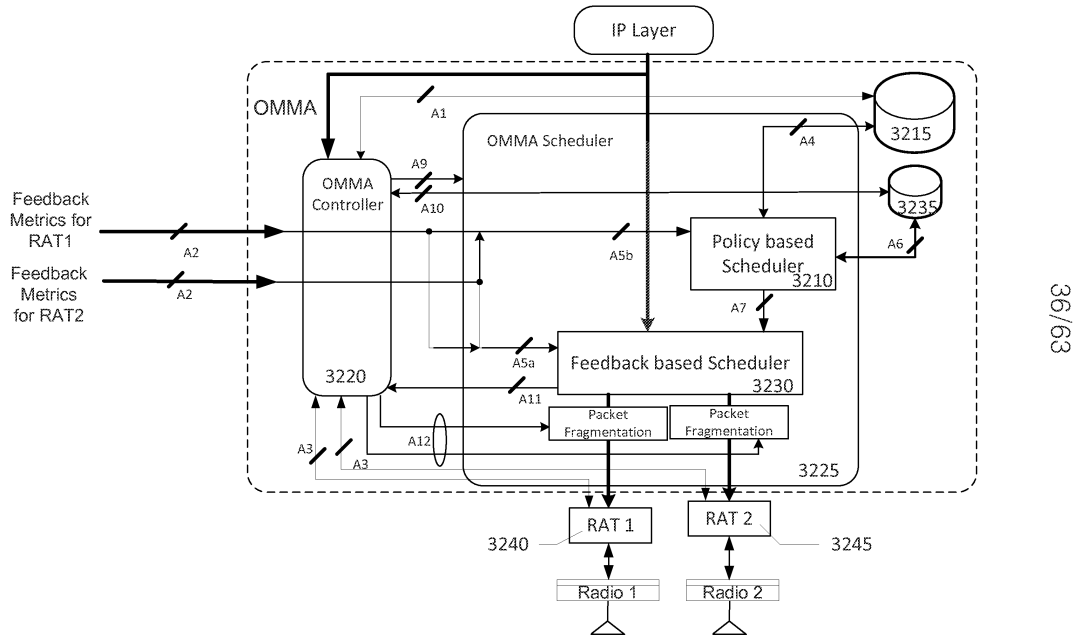


FIG. 32

SUBSTITUTE SHEET (RULE 26)

Appendix: Chincholi

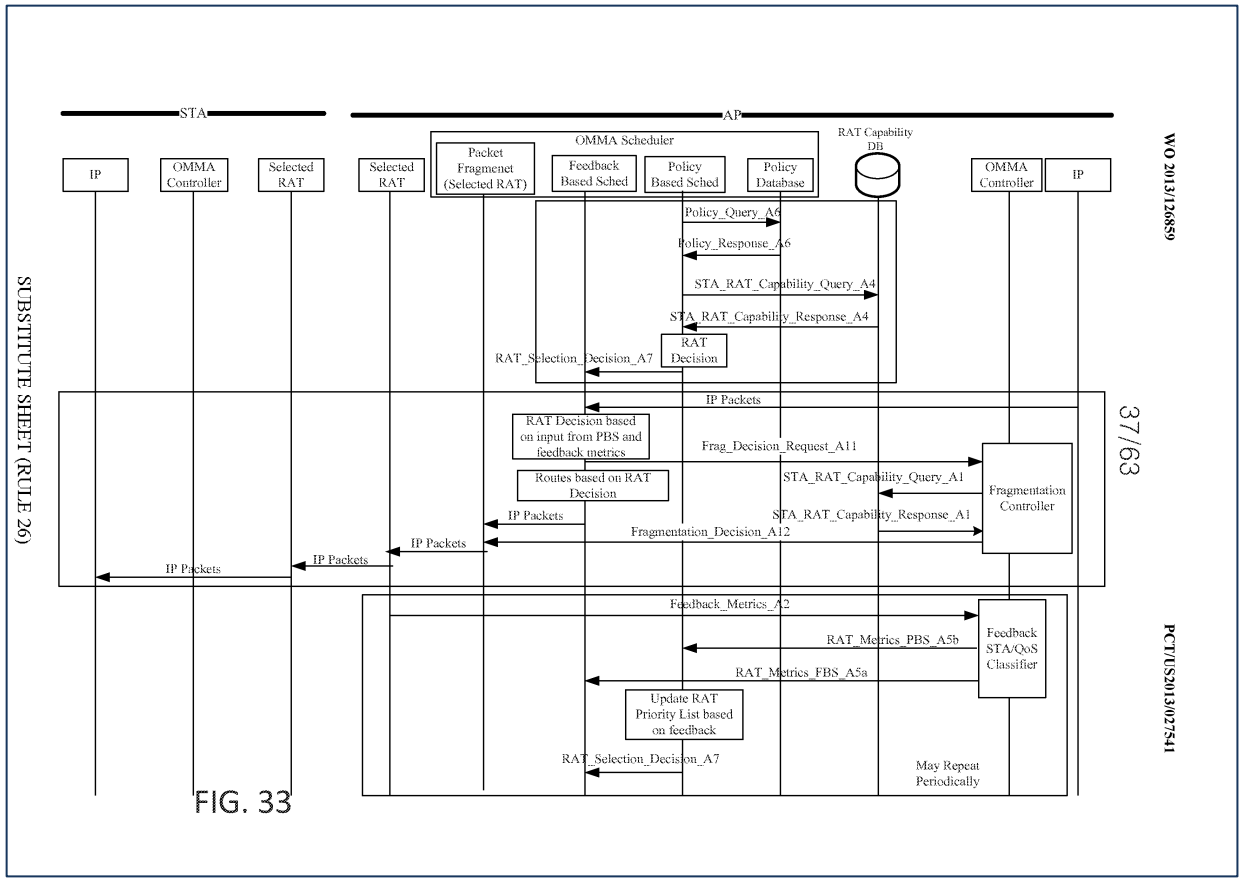


FIG. 33

SUBSTITUTE SHEET (RULE 26)
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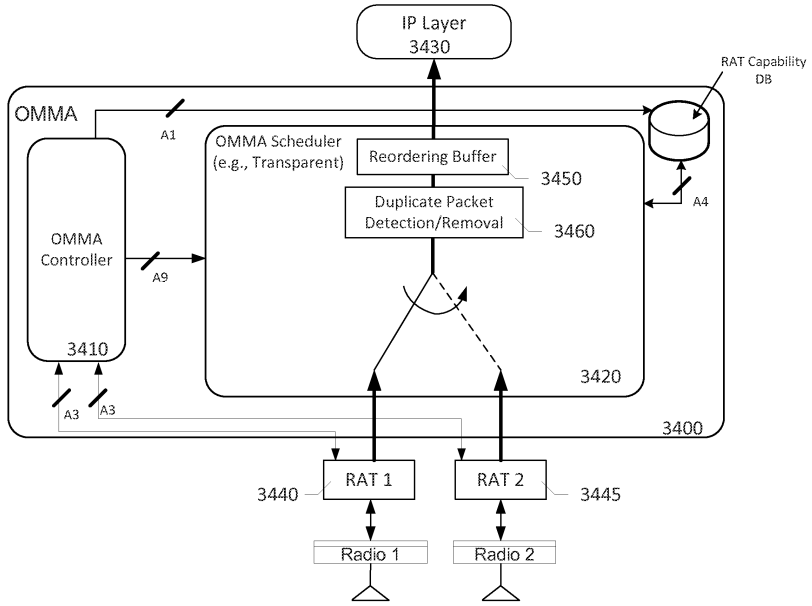


FIG. 34

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Appendix: Chincholi

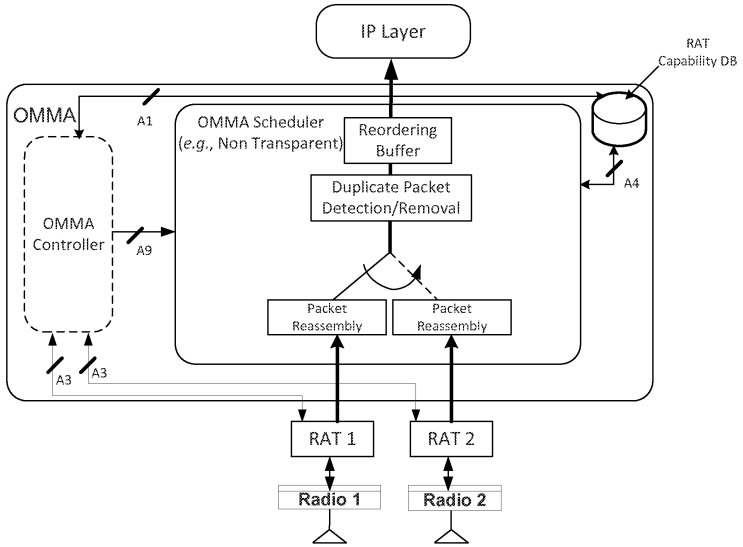


FIG. 35

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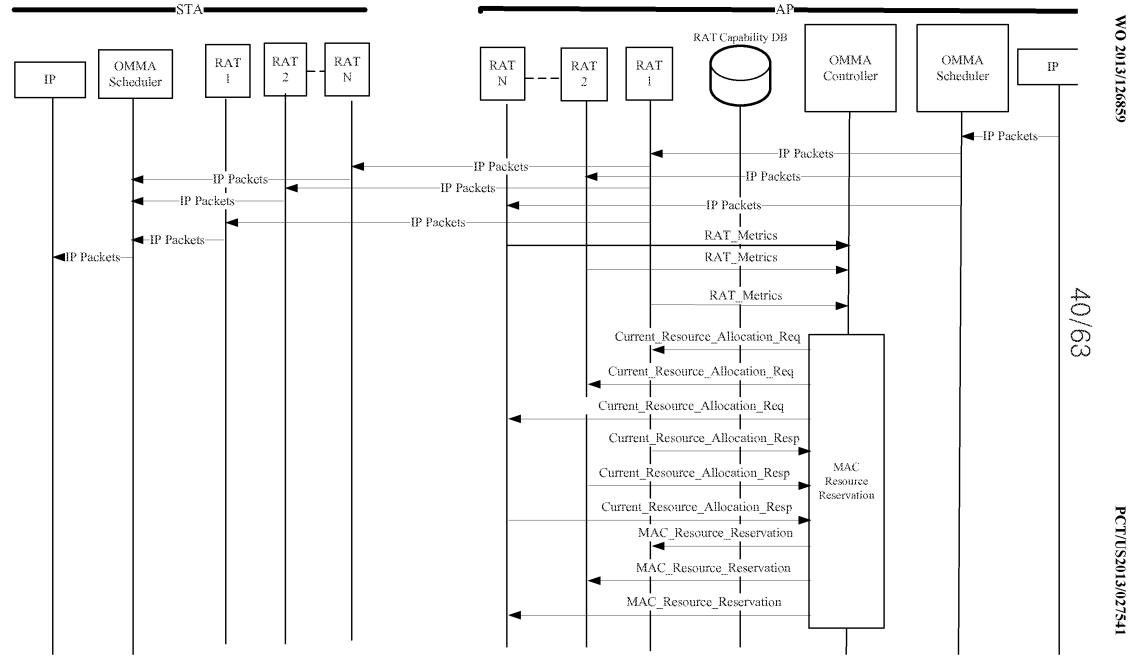


FIG. 36

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DEMONSTRATIVE EXHIBIT – NOT EVIDENCE

Appendix: Chincholi

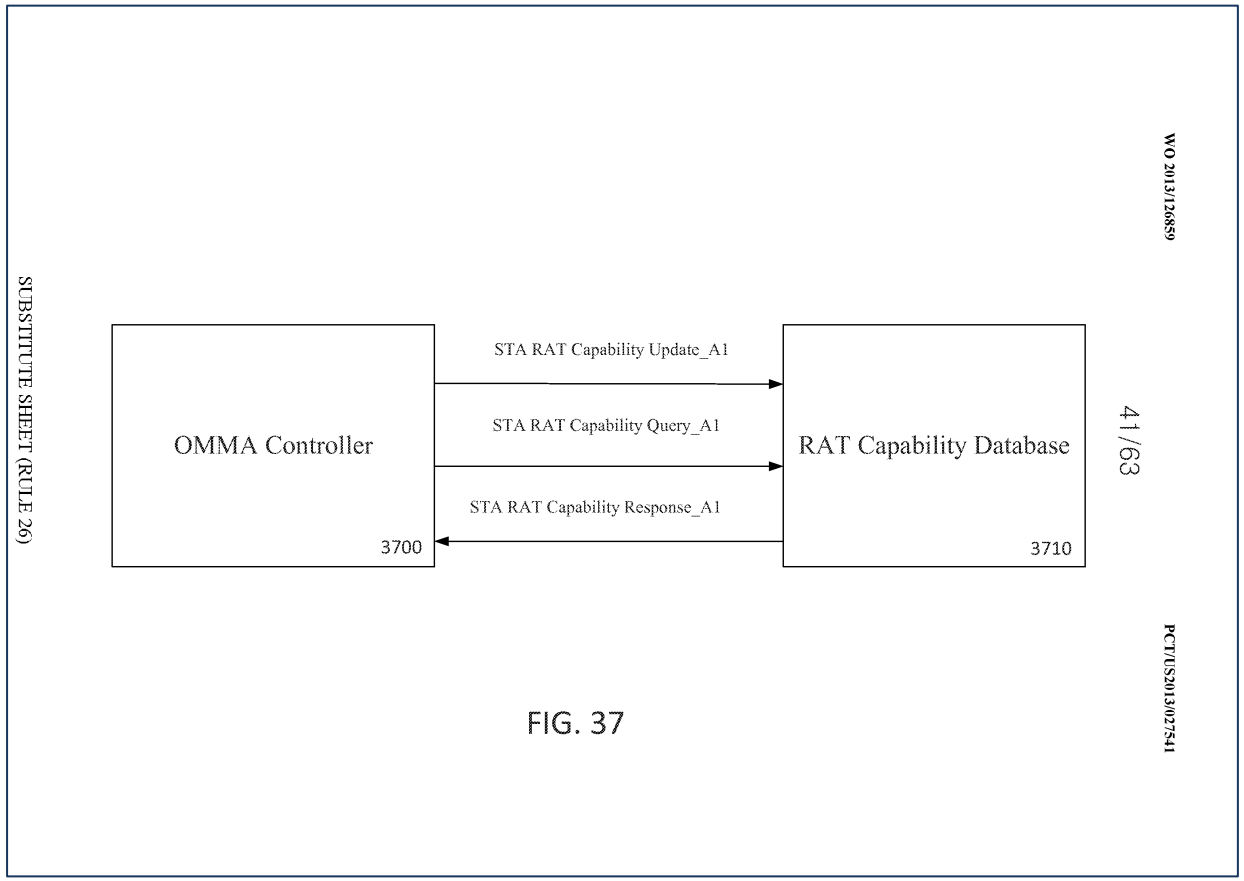


FIG. 37

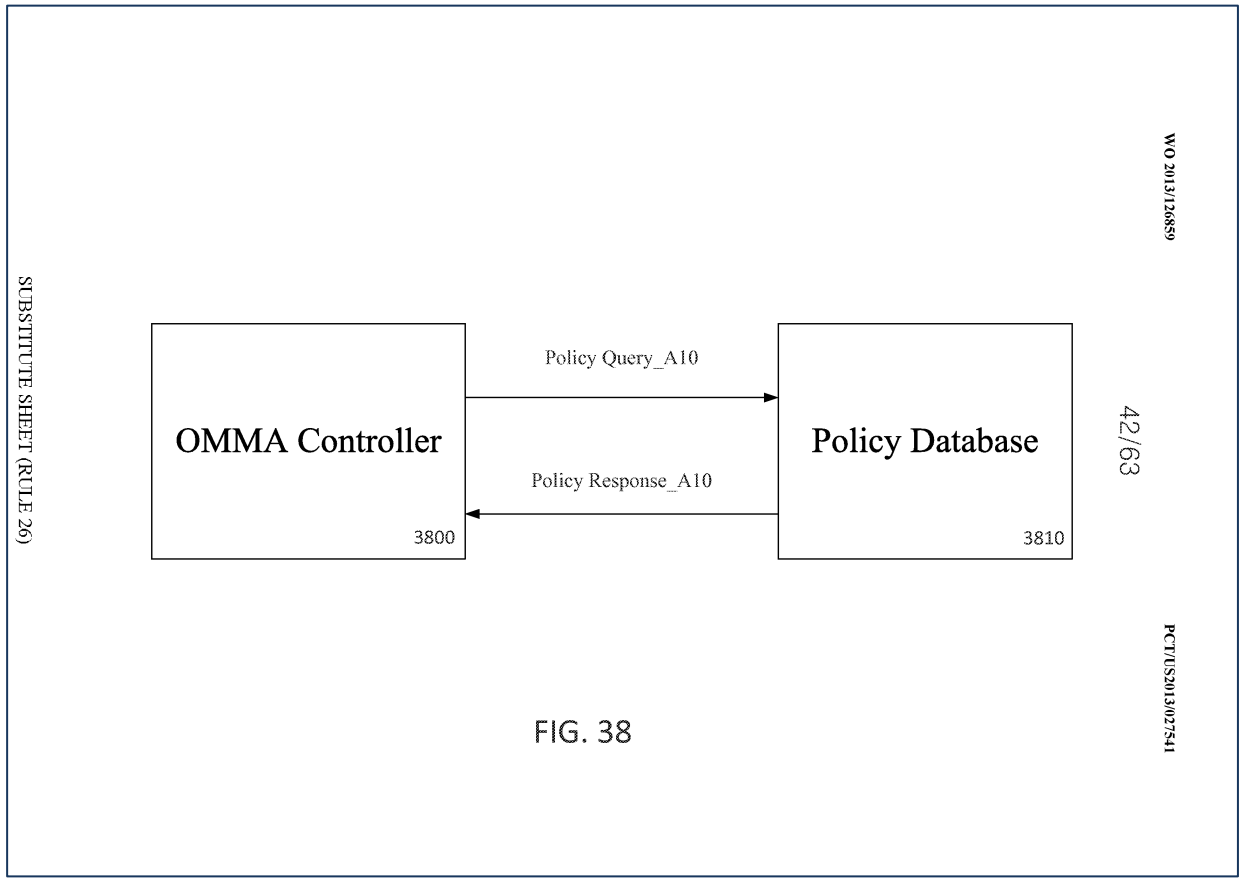


FIG. 38

Appendix: Chincholi

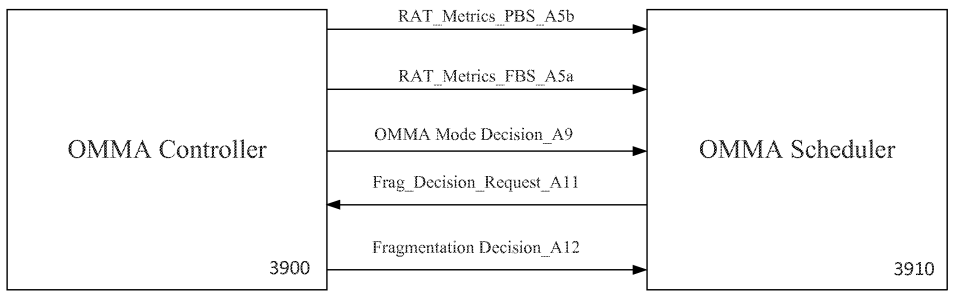


FIG. 39

Signaled Parameters

STA_Addr								
QoS_1			.....			QoS_n		
RAT_1	...	RAT_n				RAT_1	....	RAT_n
Metrics		Metrics				Metrics		Metrics

FIG. 40

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Appendix: Chincholi

Sent Parameters

STA_Addr								
QoS_1			.....			QoS_n		
RAT_1	...	RAT_n				RAT_1	....	RAT_n
Metrics		Metrics				Metrics		Metrics

FIG. 41

STA_Addr	QoS_1	Mode Decision
	.....	
	QoS_n	Mode Decision

FIG. 42

Appendix: Chincholi

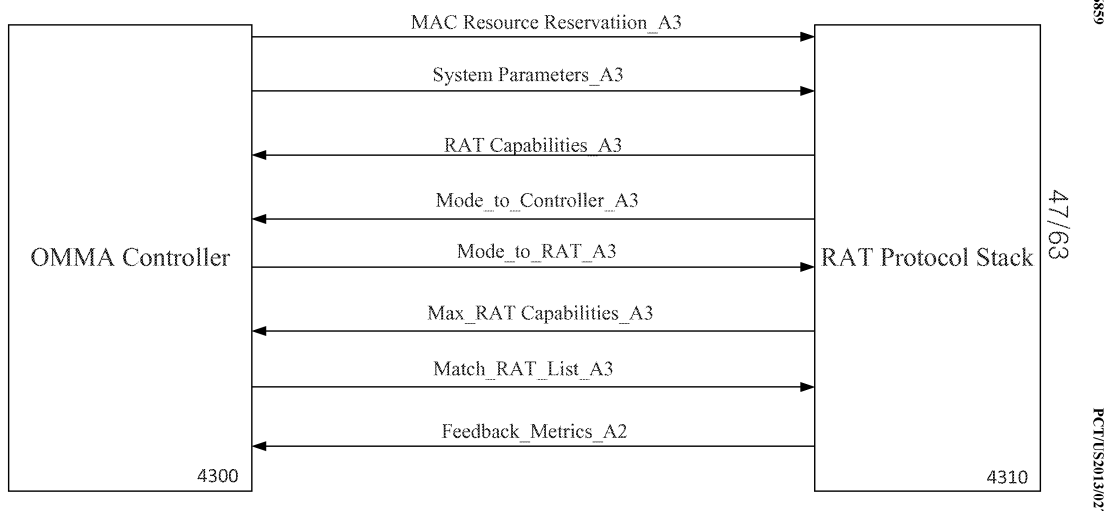


FIG. 43

RAT_ID	STA1_Addr	QoS_1	Metrics
		...	...
		QoS_n	Metrics
	.....	QoS_1	Metrics
		...	...
		QoS_n	Metrics
	STAn_Addr	QoS_1	Metrics
		...	...
		QoS_n	Metrics

FIG. 44

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Appendix: Chincholi

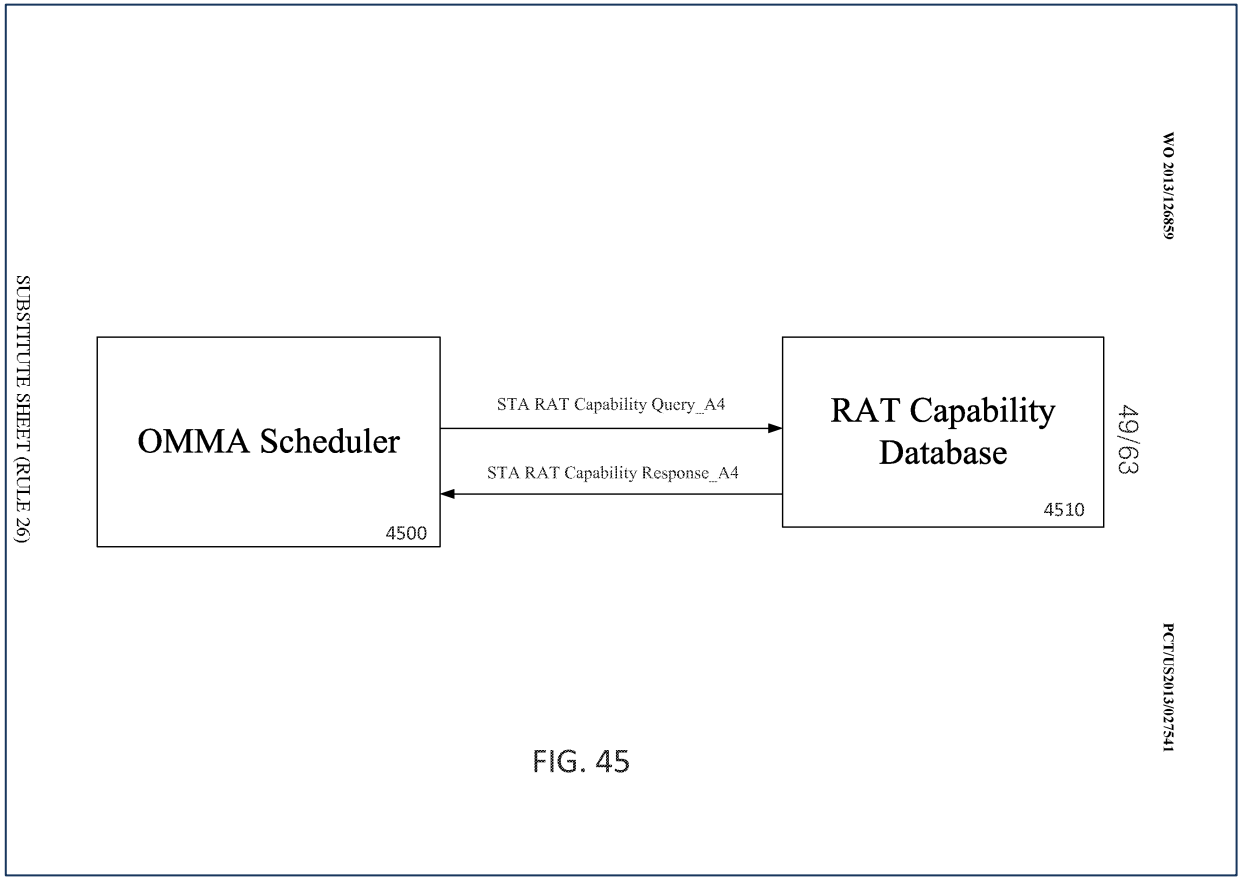


FIG. 45

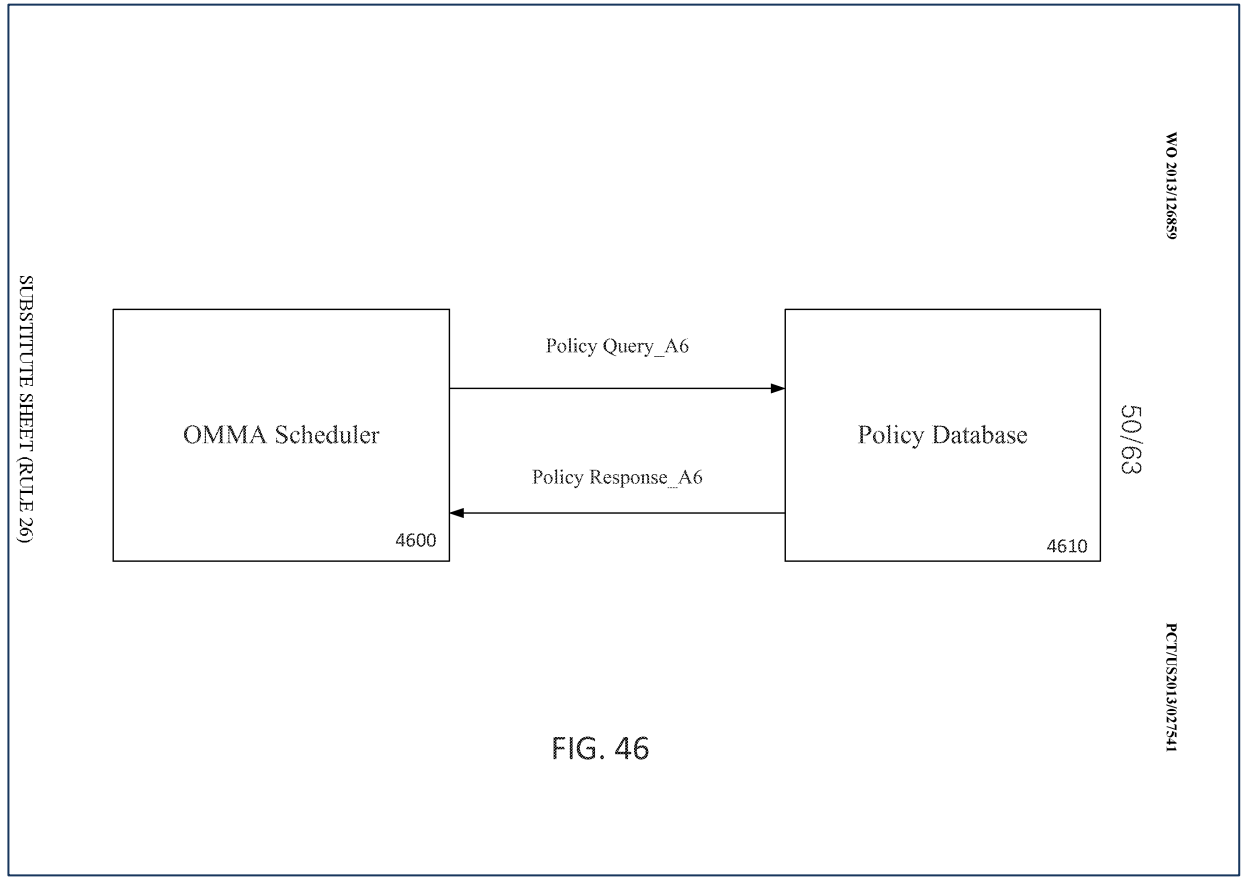


FIG. 46

Appendix: Chincholi

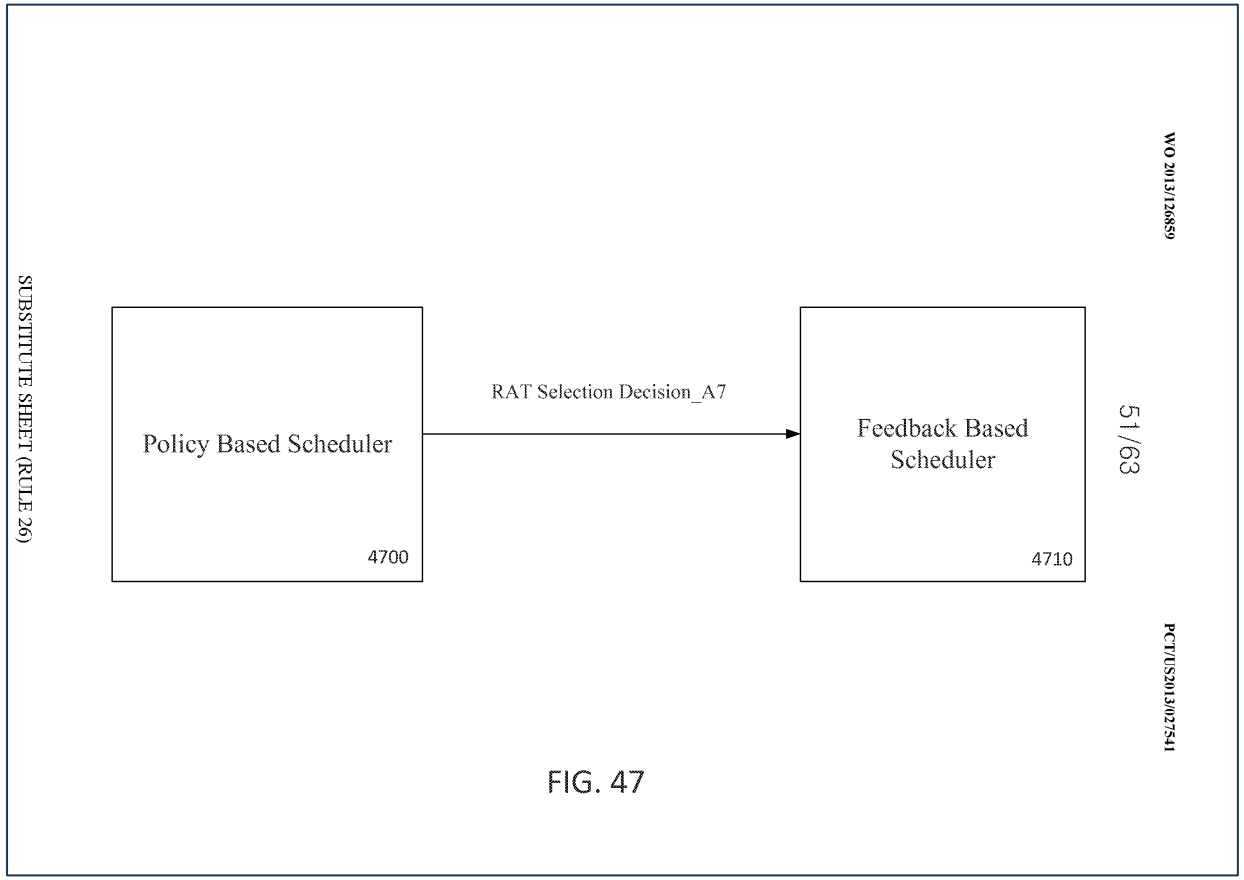


FIG. 47

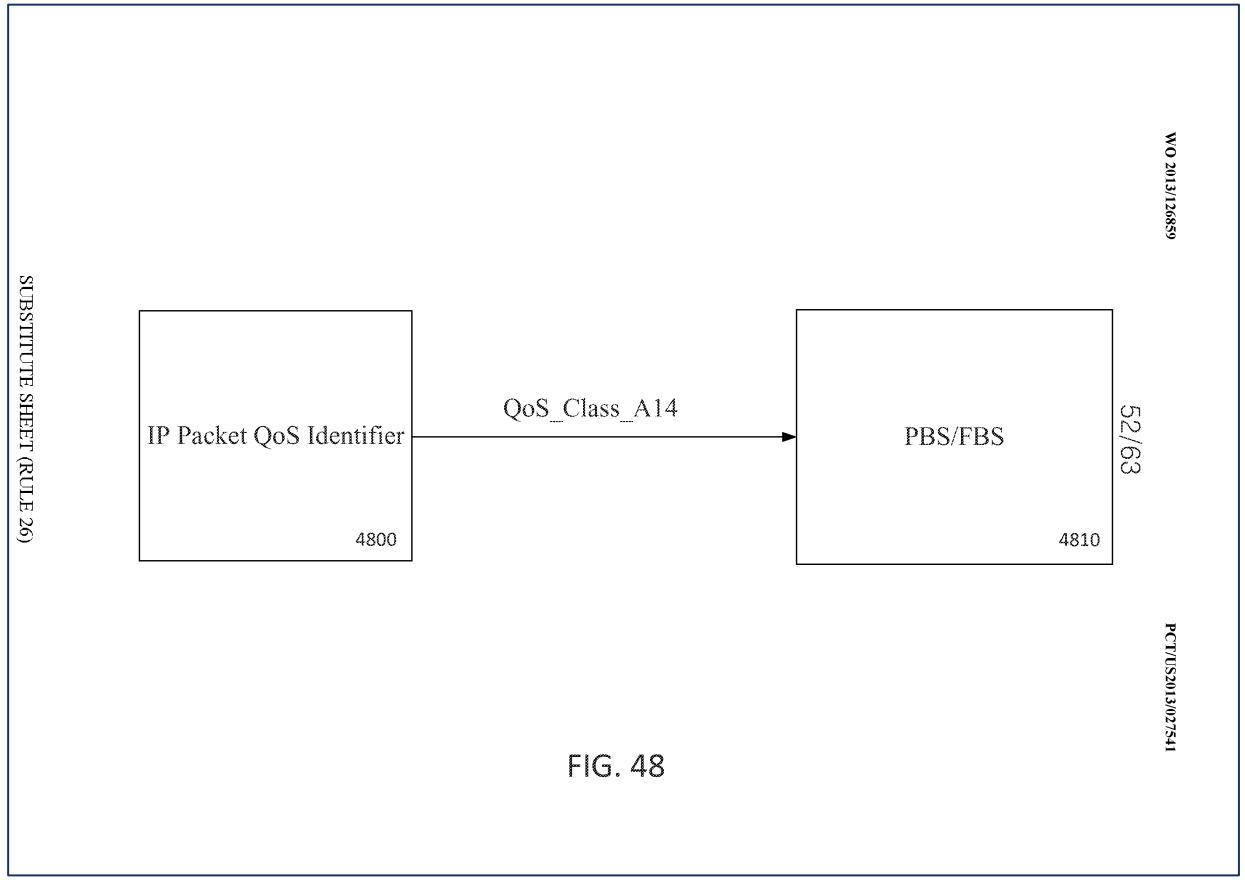


FIG. 48

Appendix: Chincholi

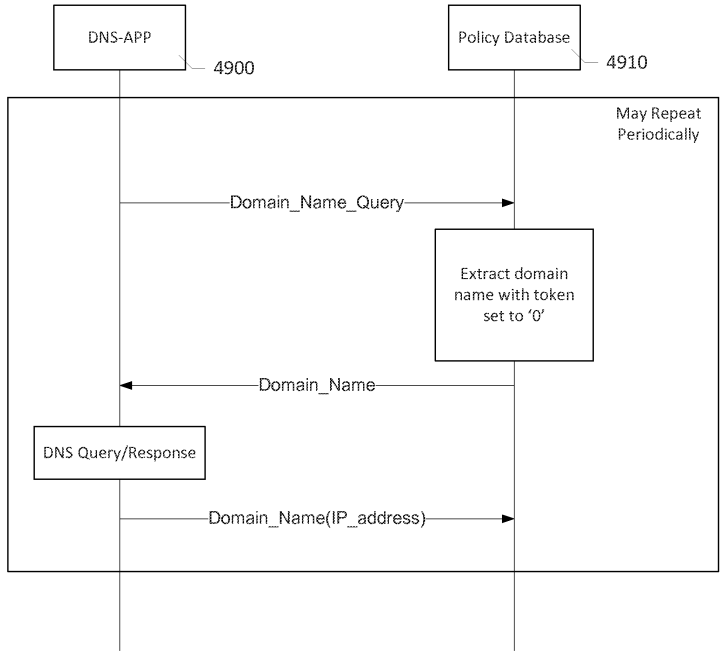


FIG. 49

SUBSTITUTE SHEET (RULE 26)

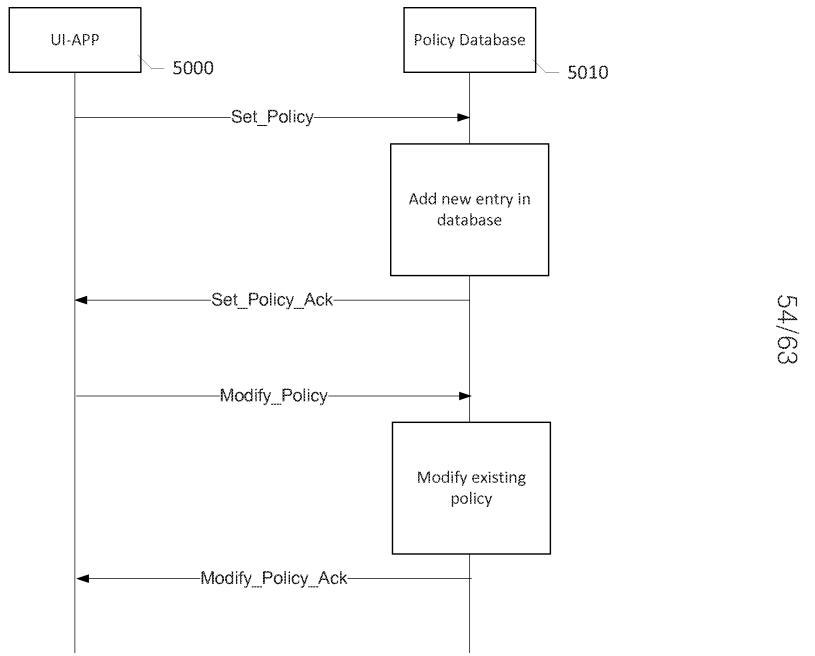


FIG. 50

SUBSTITUTE SHEET (RULE 26)

Appendix: Chincholi

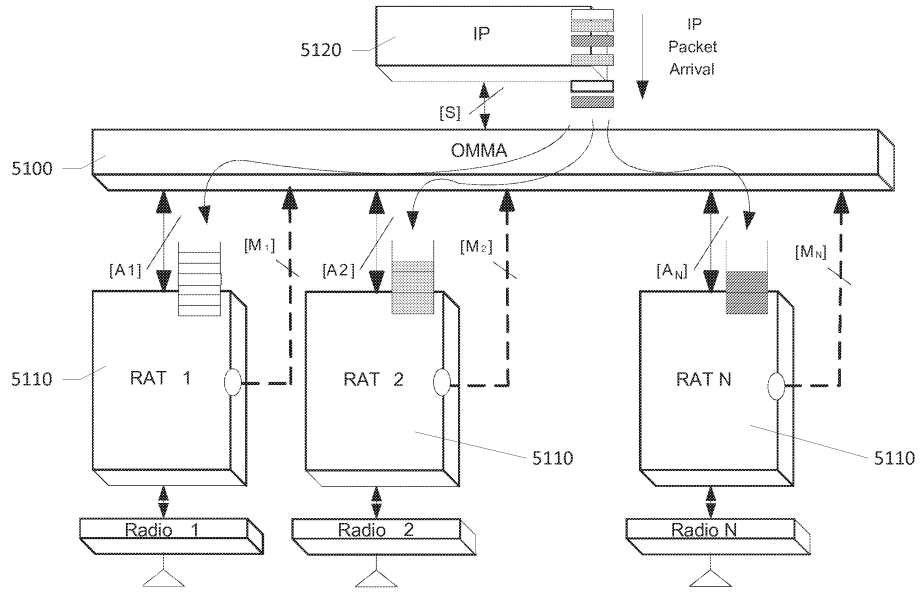


FIG. 51

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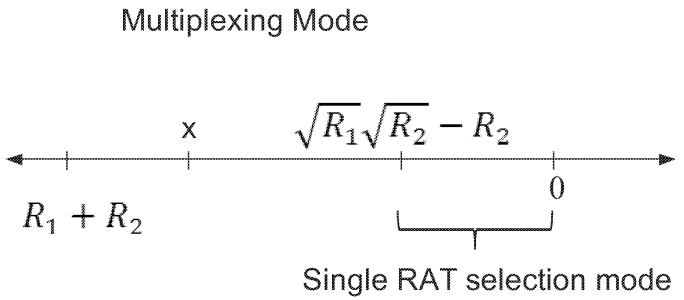


FIG. 52

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Appendix: Chincholi

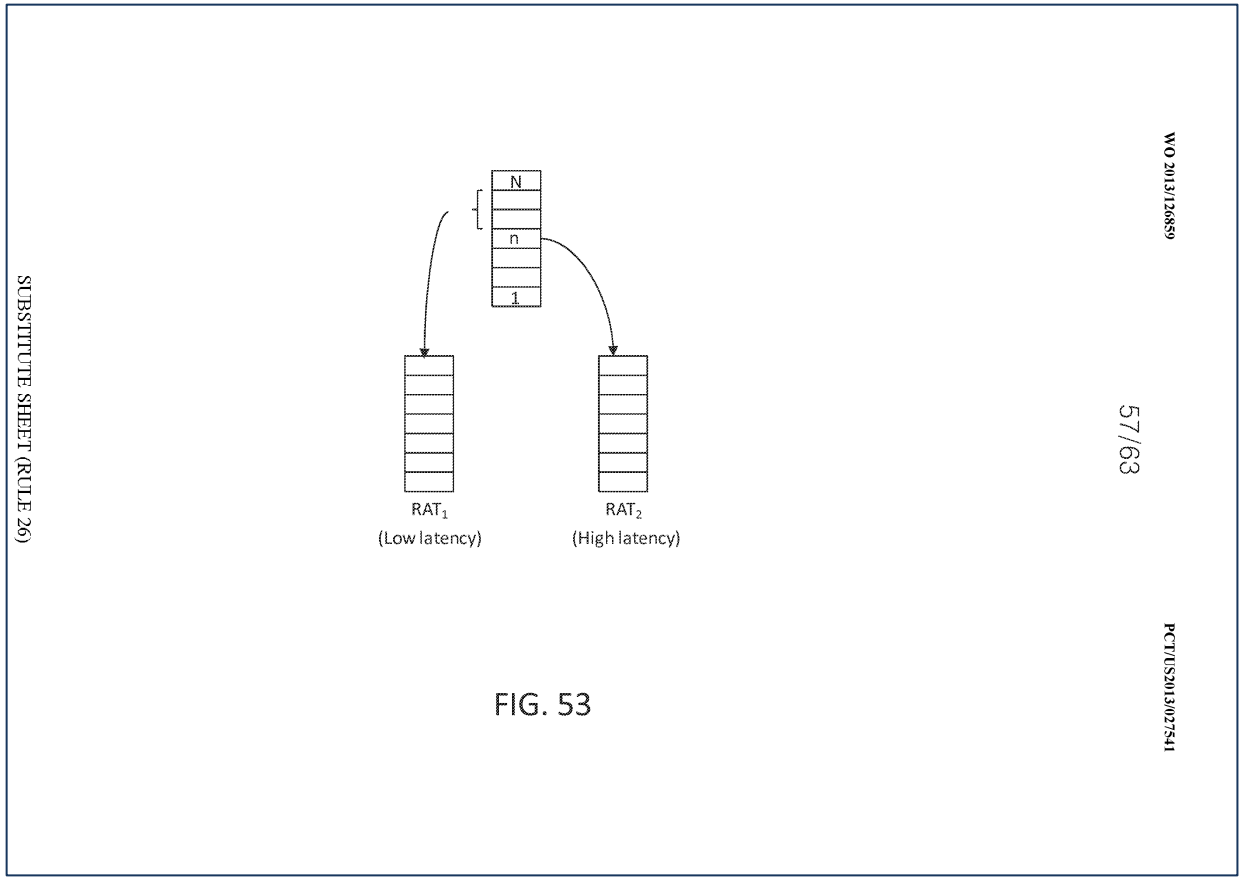


FIG. 53

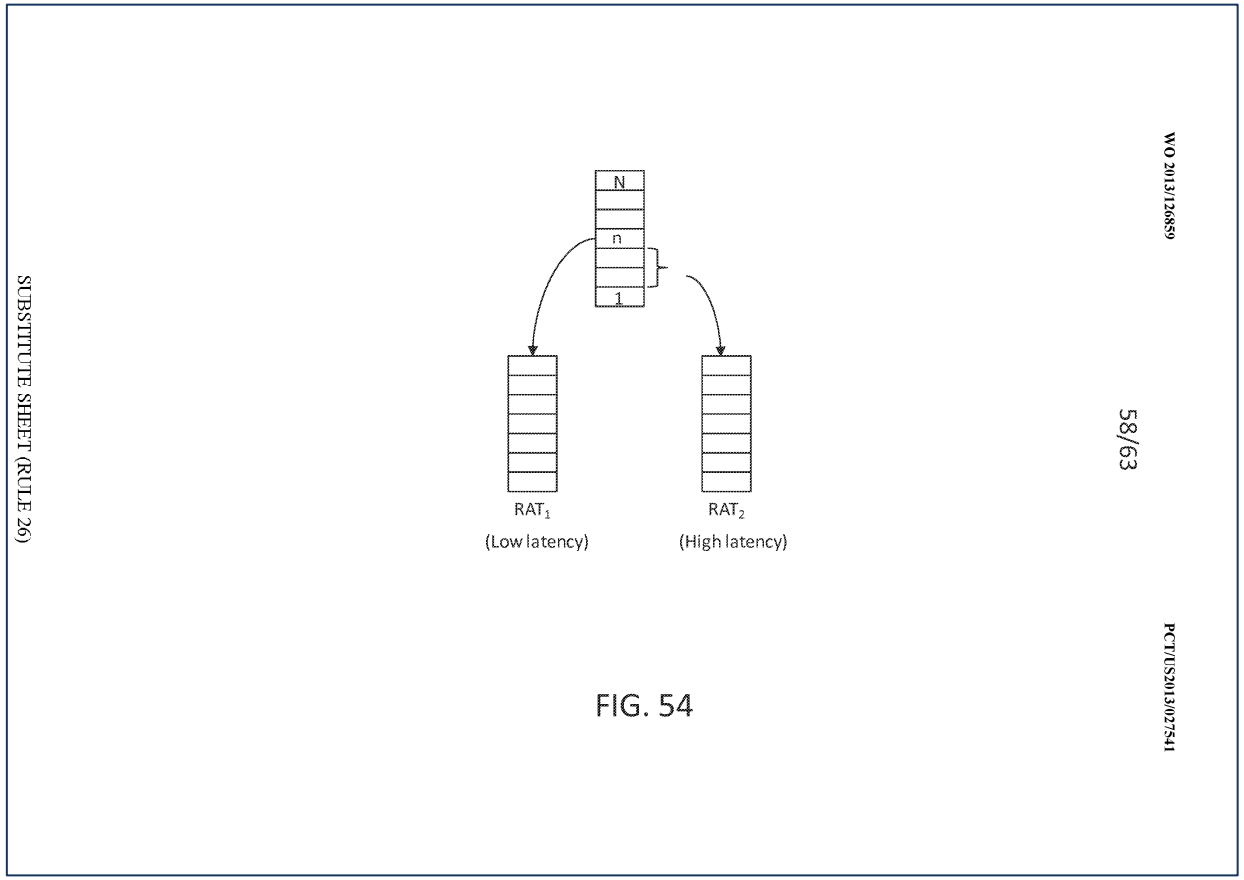
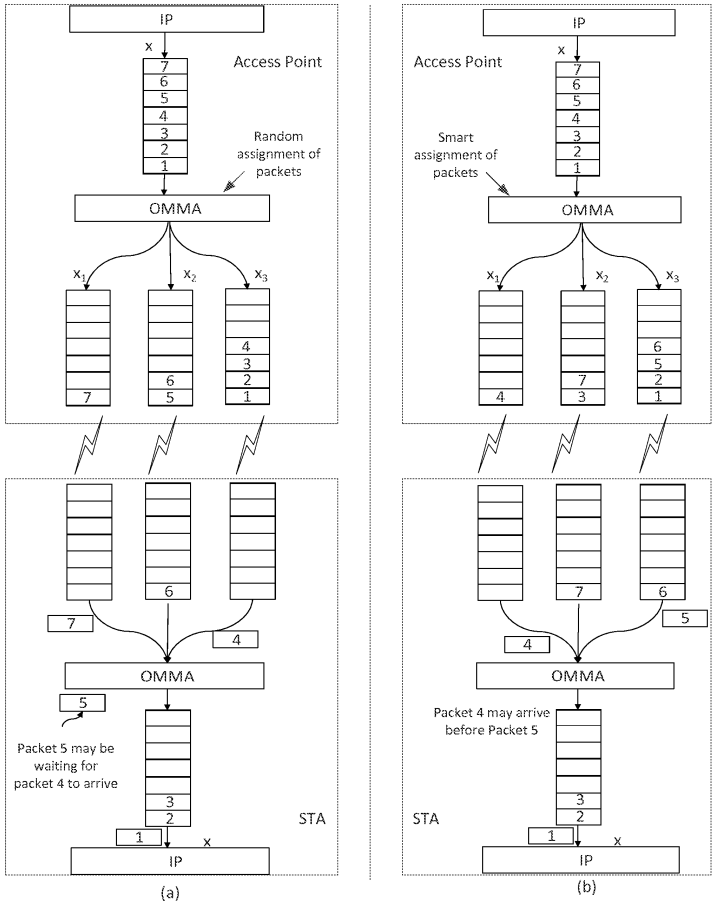


FIG. 54

Appendix: Chincholi



FIGs. 55a-b


```
Function OMMA_Smart_Packet_Allocation
Begin
    //Initialization
    For (i=1 to K) Token_i = 0;

    While (Unscheduled packets set is !Empty)
    Begin
        /* Update Value of x_i */
        For (i=1 to K)
        Begin
            Update R_i from Meta Data Feedback from MAC layer
            Update  _i from Meta Data Feedback from MAC layer
            TokenRate_i =  ;
        End For

        /*Specify the RAT to send out the current packet */
        While (Every Token_i < 1)
        Begin
            For (i=1 to K)  Token_i = Token_i + TokenRate_i
        End While
        Find j with Token_j= max{Token Set}
        Send current packet on RAT_j
        Token_j = Token_j - 1;
    End While
End Function
```

FIG. 56

DEMONSTRATIVE EXHIBIT – NOT EVIDENCE

Appendix: Chincholi

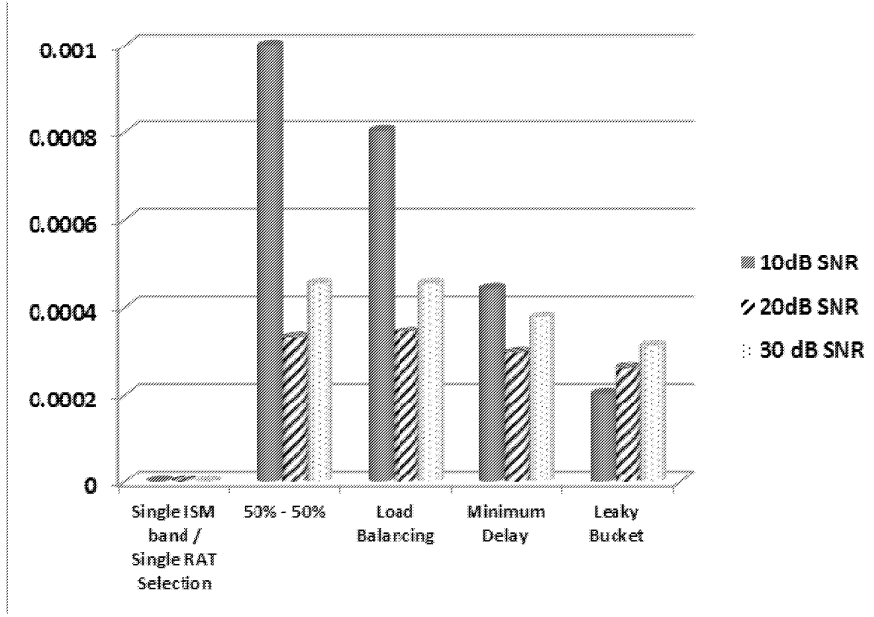


FIG. 57

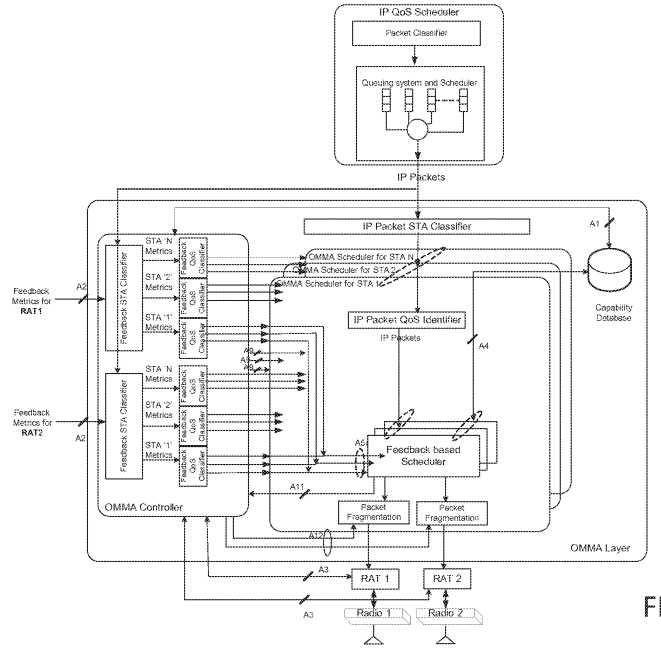


FIG. 58

Appendix: Chincholi

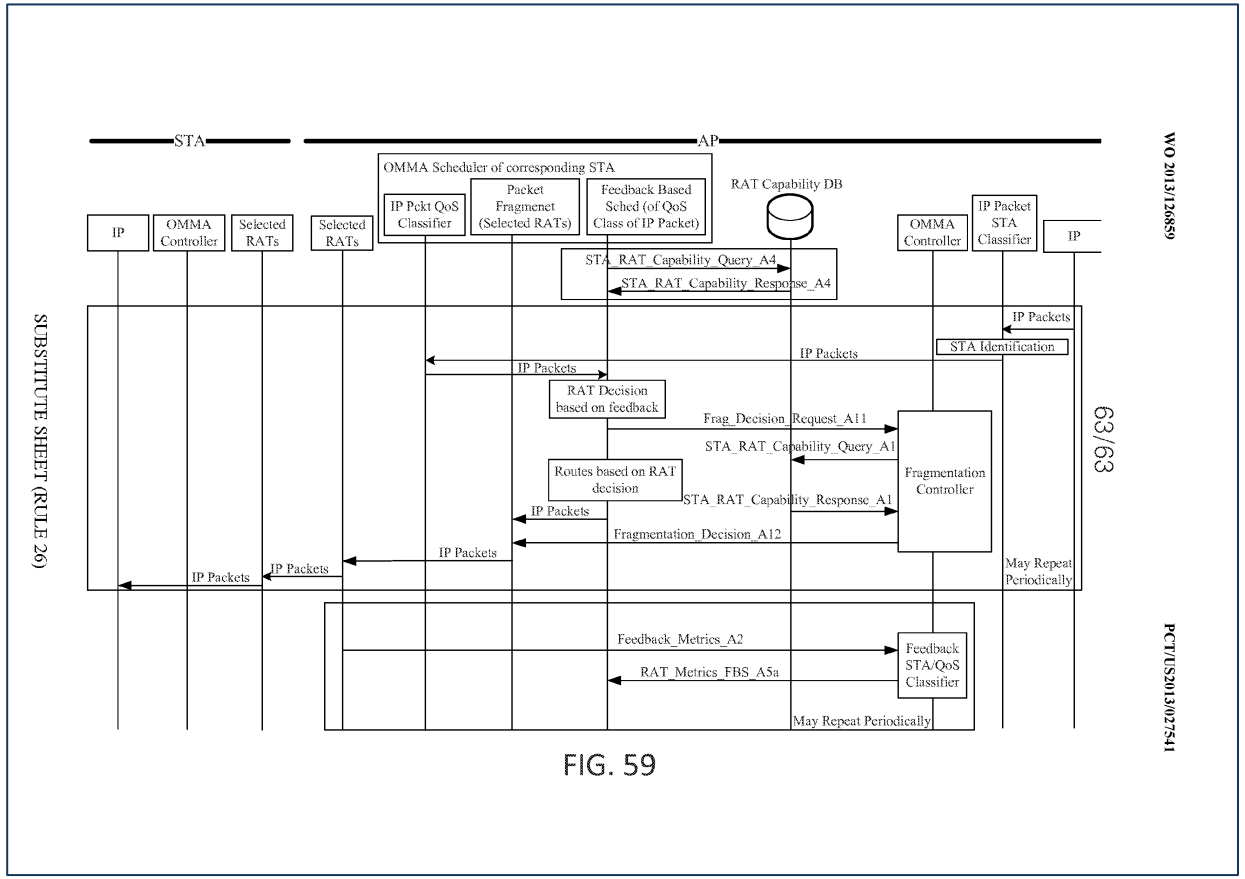


FIG. 59

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