IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent of:	Xiaobo Zhang.	Attorney Docket No. 50095-0233IP1
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Appl. Serial No.:	17/143,180	
Filing Date:	January 7, 2021	
Title:	METHOD AND DEVICE FOR MULTI-ANTENNA TRANSMISSION IN USER EQUIPMENT (UE) AND BASE STATION	

DECLARATION OF EXPERT

I declare that all statements made herein on my own knowledge are true and that all statements made on information and belief are believed to be true, and further, that these statements were made with the knowledge that willful false statements and the like so made are punishable under Section 1001 of Title 18 of the United States Code.

Date: 5-5-2025

By: _____

Dr. Narayan Mandayam

Table of Contents

I. ASSIGNMENT....4
II. QUALIFICATIONS AND BACKGROUND INFORMATION....5
III. OVERVIEW OF CONCLUSIONS FORMED....10
IV. LEGAL PRINCIPLES....11
A. Terminology....11
B. Legal Standards....11
1. Anticipation....12
2. Obviousness....12
3. Claim Construction....16
4. Level of Ordinary Skill....17
V. MATERIALS CONSIDERED....18
VI. TECHNOLOGY BACKGROUND....20
A. Wireless Network Architecture and Protocols....20
B. Antenna Systems on a UE....28
VII. THE '110 PATENT....29
A. Overview of the '110 Patent....29
B. Prosecution History of the '110 Patent....31
VIII. OVERVIEW AND COMBINATIONS OF PRIOR ART REFERENCES....31
A. Overview of Kim....31
B. Overview of Dahlman....34
C. Overview of Kim-966....35
D. Combination of Kim, Dahlman, and Kim-966....37
IX. MANNER IN WHICH THE PRIOR ART REFERENCES RENDER THE '110 CLAIMS UNPATENTABLE....54
A. Analysis - [GROUND 1] – [Kim, Dahlman, Kim-966]....54
1. Claim 1....54
2. Claim 2....79
3. Claim 3....86
4. Claim 4....87
5. Claim 5....91
6. Claim 6....93
7. Claim 7....95
8. Claim 8....96
9. Claim 9....97
10. Claim 10....98

11. Claim 11 98
12. Claim 12 100
13. Claim 13 101
14. Claim 14 101
15. Claim 15 102
16. Claim 16 102
17. Claim 17 104
18. Claim 18 104
19. Claim 19 105
20. Claim 20 105

X. CONCLUSION.....106

I, Narayan Mandayam declare and state as follows:

I. ASSIGNMENT

1. I have been retained by counsel for Petitioner Apple Inc. ("Petitioner" or "Apple") as a technical expert in the above matter. I am submitting this Declaration to address the validity of claims 1-20 ("Challenged Claims") in U.S. Patent No. 11,546,110 ("the '110 patent"). For the purposes of this Declaration, I have not been asked to opine on any other issues not addressed below.

2. My opinions are based on my years of education, research and experience, as well as my investigation and study of relevant materials, including those identified in this Declaration. I may rely upon these materials, my knowledge and experience, and/or additional materials in forming any necessary opinions. Further, I may also consider additional documents and information to rebut arguments raised by the Patent Owner Apex Beam Technologies LLC ("Patent Owner" or "Apex"). I reserve any right that I may have to supplement this Declaration if further information becomes available or if I am asked to consider additional information. Furthermore, I reserve any right that I may have to consider and comment on any additional expert statements or testimony of Apex's expert(s) in this matter.

3. My analysis of the materials produced in this investigation is ongoing and I will continue to review any new material as it is provided. This Declaration

represents only those opinions I have formed to date. I reserve the right to revise, supplement, and/or amend my opinions stated herein based on new information and on my continuing analysis of the materials already provided.

4. I am not and never have been, an employee of Apple. I received no compensation for this declaration beyond my normal hourly compensation based on my time actually spent analyzing the ‘110 patent, the prior art publications cited below, and issues related thereto, and I will not receive any added compensation based on the outcome of any IPR or other proceeding involving the ‘110 patent.

II. QUALIFICATIONS AND BACKGROUND INFORMATION

5. I am an independent consultant. All of my opinions stated in this declaration are based on my own personal knowledge and professional judgment. In forming my opinions, I have relied on my knowledge and extensive experience in the field of telecommunications networks, algorithms, and communication protocols.

6. I am over the age of 18 and am competent to write this declaration. I have personal knowledge, or have developed knowledge of these technologies based upon education, training, or experience, of the matters set forth herein.

7. My qualifications are summarized here and explained in more detail in my curriculum vitae, which is attached as Appendix A to this report.

8. I am a Distinguished Professor of Electrical and Computer

Engineering at Rutgers University where I serve as the Director of the Wireless Information Network Laboratory (WINLAB), a world class wireless networking research center at Rutgers University. WINLAB has been serving as an industry-university cooperative research center since its inception in 1989. I have been writing, researching and teaching about wireless communications and networking since 1989.

9. I received my Bachelor's degree in Electrical Engineering from the Indian Institute of Technology (IIT) in Kharagpur, India in 1989 with honors. I received my M.S. in Electrical Engineering from Rice University in 1991 and my Ph. D in Electrical Engineering in 1994, also from Rice University. After completing my studies, I was hired as a Research Associate at WINLAB in 1994 before being hired as an Assistant Professor in 1996 in the Department of Electrical and Computer Engineering at Rutgers University. I was promoted to Associate Professor in 2001, to Professor in 2003, and to Distinguished Professor in 2014.

10. I also served as the Peter D. Cherasia Endowed Faculty Scholar at Rutgers University from 2010 to 2014, the Chair of the Electrical and Computer Engineering Department from 2016 to 2022, and as an Associate Director at WINLAB since 1999. I was a visiting faculty fellow in the Department of Electrical Engineering at Princeton University in Fall 2002, and a visiting faculty

at the Indian Institute of Science in Spring 2003.

11. I conduct research in various aspects of wireless systems and networks. I teach courses at Rutgers on the topics of Wireless System Design, Wireless Communication Technologies, Wireless Revolution, Detection and Estimation Theory and Introduction to Computing for Engineers. I have co-authored 2 books on wireless networks (Principles of Cognitive Radio, Cambridge (2012) and Wireless Networks: Multiuser Detection in Cross-Layer Design, Springer (2005)), 8 book chapters and published nearly 300 papers in prestigious international journals and conferences. I have also given numerous invited presentations at a variety of industry, government, and academic forums.

12. Over the last 30 years, I have published a wide range of articles on various aspects of wireless systems addressing PHY, MAC and Network layer issues including techniques for data transmission and multimedia communications, resource allocation strategies, algorithms for wireless network security, mathematical modeling, and performance analysis. Using constructs from game theory, communications, and networking, my work has focused on system modeling and performance, signal processing as well as radio resource management for enabling wireless technologies to support various applications.

13. I have made seminal research contributions to wireless data communications on issues ranging from the systems level (such as power control,

base station assignment, capacity evaluation, protocol design, medium access control, and radio resource management) to the physical layer (such as data transmission and reception). I have also done seminal work in the area of the Physical-Layer security, where properties of the radio channel (PHY layer of the protocol stack) are exploited for the purposes of secret key generation, authentication and encryption. One of my papers on this topic is also featured in the Best Readings compilation of the IEEE Communications Society (COMSOC) as the top paper on Physical-Layer Authentication. My expertise includes cellular systems such as for 2G, 3G, 4G, 5G, and I have published papers on a wide variety of topics related to the design and operation of GSM/TDMA, CDMA and LTE and 5G based systems. During this time, I have also worked extensively on wireless local area network (WLAN) and Wi-Fi technologies as well as wireless ad-hoc and sensor networks, and as such, I am quite familiar with 802.11 and Bluetooth.

14. I have also served as a technical consultant since its inception in 2002 to the company Mojo Networks Inc. (recently acquired by Arista Networks), a world leader in enterprise network security for WLANs and Wi-Fi networks that offers the next generation of intelligent edge, secure, and flexible Wi-Fi solutions. I am familiar with the early developments in the area of cellular systems (2G, 3G, 4G and 5G) and have served on several graduate thesis defense committees pertaining to all aspects of wireless systems operation.

15. I have received several prestigious awards relating to my research on wireless networks and communications: the 2015 IEEE COMSOC Advances in Communications Award for seminal work on power control in wireless data networks (this is the highest paper award given by the IEEE Communications Society to the most impactful publication in the preceding 15 years), the 2014 IEEE Donald G. Fink Award (recognizes the most outstanding tutorial paper across all IEEE publications) for the paper titled "Frontiers of Wireless and Mobile Communications" that discusses the historical and future landscape of both WAN and LAN wireless technologies, and the Fred W. Ellersick Prize from the IEEE Communications Society in 2009 for work on dynamic spectrum access models and spectrum policy. I also received the Peter D. Cherasia Faculty Scholar Award from Rutgers University in 2010, the National Science Foundation Career Award in 1998, the Institute Silver Medal from the Indian Institute of Technology, Kharagpur, in 1989, and its Distinguished Alumnus Award in 2018.

16. I have served as an Editor for the journals IEEE Communication Letters (1999- 2002) and IEEE Transactions on Wireless Communications (2002-2004). I have also served as a guest editor of the IEEE JSAC Special Issues on Adaptive, Spectrum Agile and Cognitive Radio Networks (2007) and Game Theory in Communication Systems (2008). I was elected Fellow of the IEEE for "contributions to wireless data transmission." I have also served as a Distinguished

Lecturer of the IEEE Communications Society.

17. My experience of over 30 years with networking and telecommunications in academic and practical situations as well as my hands on experience, has given me a detailed appreciation of the technology involved with the ‘110 patent.

18. My opinions, as explained below, are based on my education, experience, and expertise in the fields relating to the ‘110 Patent. Unless otherwise stated, my testimony below refers to the knowledge of one of ordinary skill in the art as of the earliest possible priority date. Any figures that appear within this document have been prepared with the assistance of Counsel and reflect my understanding of the ‘110 Patent and the prior art discussed below.

III. OVERVIEW OF CONCLUSIONS FORMED

19. This declaration explains the conclusions that I have formed based on my analysis of all of the considered materials and my personal experience. To summarize those conclusions, based upon my knowledge and experience and my review of the prior art references listed above, I believe that:

- Ground 1: Claims 1-20 unpatentable in view of Kim, Dahlman, and Kim-966

20. In support of these conclusions, I provide an overview of the references in Section VIII and more detailed comments regarding the obviousness

of claims 1-20 ("the Challenged Claims") of the '110 patent in Sections IX-X.

IV. LEGAL PRINCIPLES

A. Terminology

21. I have been informed by Counsel and understand that the best indicator of claim meaning is its usage in the context of the patent specification as understood by one of ordinary skill. I further understand that the words of the claims should be given their plain meaning unless that meaning is inconsistent with the patent specification or the patent's history of examination before the Patent Office. Counsel has also informed me, and I understand that, the words of the claims should be interpreted as they would have been interpreted by one of ordinary skill at the time of the invention was made (not today). The '110 patent was filed June 3, 2019 and claims priority to Chinese Application No. 201611098328.7, filed December 3, 2016 , which I refer to as the "Critical Date" in this proceeding. Because I do not know at what date the invention as claimed was made, if ever, I have used the Critical Date of the '110 patent as the point in time for claim interpretation purposes. My opinion does not change if the invention date is earlier.

B. Legal Standards

22. I have been informed by Counsel and understand that documents and materials that qualify as prior art can render a patent claim unpatentable as being anticipated or obvious.

23. I am informed by Counsel and understand that all prior art references are to be looked at from the viewpoint of a person of ordinary skill in the art at the time of the invention, and that this viewpoint prevents one from using his or her own insight or hindsight in deciding whether a claim is anticipated or rendered obvious.

1. **Anticipation**

24. I understand that patents or printed publications that qualify as prior art can be used to invalidate a patent claim as anticipated or as obvious.

25. I understand that, once the claims of a patent have been properly construed, the second step in determining anticipation of a patent claim requires a comparison of the properly construed claim language to the prior art on a limitation-by-limitation basis.

26. I understand that a prior art reference "anticipates" an asserted claim, and thus renders the claim invalid, if all limitations of the claim are disclosed in that prior art reference, either explicitly or inherently (i.e., necessarily present).

2. **Obviousness**

27. I understand that even if a patent is not anticipated, it is still invalid if the differences between the claimed subject matter and the prior art are such that the subject matter as a whole would have been obvious to a POSITA at the time the invention was made.

28. I have been informed by Counsel and understand that a claim is unpatentable for obviousness and that obviousness may be based upon a combination of references. I am informed by Counsel and understand that the combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results. However, I am informed by Counsel and understand that a patent claim composed of several elements is not proved obvious merely by demonstrating that each of its elements was, independently, known in the prior art.

29. I am informed by Counsel and understand that when a patented invention is a combination of known elements, a court determines whether there was an apparent reason to combine the known elements in the fashion claimed by the patent at issue by considering the teachings of prior art references, the effects of demands known to people working in the field or present in the marketplace, and the background knowledge possessed by a person having ordinary skill in the art.

30. I am informed by Counsel and understand that a patent claim composed of several limitations is not proved obvious merely by demonstrating that each of its limitations was independently known in the prior art. I am informed by Counsel and understand that identifying a reason those elements would be combined can be important because inventions in many instances rely

upon building blocks long since uncovered, and claimed discoveries almost of necessity will be combinations of what, in some sense, is already known. I am informed by Counsel and understand that it is improper to use hindsight in an obviousness analysis, and that a patent's claims should not be used as a "roadmap."

31. I am informed by Counsel and understand that an obviousness inquiry requires consideration of the following factors: (1) the scope and content of the prior art, (2) the differences between the prior art and the claims, (3) the level of ordinary skill in the art, and (4) any so called "secondary considerations" of non-obviousness, which include: (i) "long felt need" for the claimed invention, (ii) commercial success attributable to the claimed invention, (iii) unexpected results of the claimed invention, and (iv) "copying" of the claimed invention by others.

32. I have been informed by Counsel and understand that an obviousness evaluation can be based on a single reference or a combination of multiple prior art references. I understand that the prior art references themselves may provide a suggestion, motivation, or reason to combine, but that the nexus linking two or more prior art references is sometimes simple common sense. I have been informed by Counsel and understand that obviousness analysis recognizes that market demand, rather than scientific literature, often drives innovation, and that a motivation to combine references may be supplied by the direction of the marketplace.

33. I have been informed by Counsel and understand that if a technique has been used to improve one device, and a person of ordinary skill at the time of invention would have recognized that it would improve similar devices in the same way, using the technique is obvious unless its actual application is beyond his or her skill.

34. I have been informed by Counsel and understand that practical and common sense considerations should guide a proper obviousness analysis, because familiar items may have obvious uses beyond their primary purposes. I have been informed by Counsel and understand that a person of ordinary skill looking to overcome a problem will often be able to fit together the teachings of multiple prior art references. I have been informed by Counsel and understand that obviousness analysis therefore takes into account the inferences and creative steps that a person of ordinary skill would have employed at the time of invention.

35. I have been informed by Counsel and understand that a proper obviousness analysis focuses on what was known or obvious to a person of ordinary skill at the time of invention, not just the patentee. Accordingly, I understand that any need or problem known in the field of endeavor at the time of invention and addressed by the patent can provide a reason for combining the elements in the manner claimed.

36. I have been informed by Counsel and understand that a claim can be

obvious in light of a single reference, without the need to combine references, if the elements of the claim that are not found explicitly or inherently in the reference can be supplied by the common sense of one of skill in the art.

37. In sum, my understanding is that prior art teachings are properly combined where one of ordinary skill having the understanding and knowledge reflected in the prior art and motivated by the general problem facing the inventor, would have been led to make the combination of elements recited in the claims. Under this analysis, the prior art references themselves, or any need or problem known in the field of endeavor at the time of the invention, can provide a reason for combining the elements of multiple prior art references in the claimed manner.

38. I have been informed by Counsel and understand that in an *inter partes* review, "the petitioner shall have the burden of proving a proposition of unpatentability," including a proposition of obviousness, "by a preponderance of the evidence." 35 U.S.C. §316(e).

3. **Claim Construction**

39. I understand that the words of a claim are generally given their ordinary and customary meaning, which I understand is the meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention, *i.e.*, as of the effective filing date of the patent application. I understand the person of ordinary skill in the art is deemed to read the claim term not only in

the context of the particular claim in which the disputed term appears, but in the context of the entire patent, including the specification and prosecution history. Additionally, I understand other extrinsic evidence external to the patent and prosecution history, such as dictionaries and treatises, may also be useful in determining the meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention. I understand that such extrinsic evidence, however, is generally afforded less weight than intrinsic evidence in determining the meaning of claim terms, and overall is unlikely to result in a reliable interpretation of a patent claim scope unless considered in the context of the intrinsic evidence.

4. **Level of Ordinary Skill**

40. I understand there is a concept in patent law known as a person having ordinary skill in the art (POSITA). I understand that this concept refers to a person who is trained in the relevant technical field of a patent without possessing extraordinary or otherwise exceptional skill. I further understand that factors such as the education level of those working in the field, the sophistication of the technology, the types of problems encountered in the art, prior art solutions to those problems, and the speed at which innovations are made may help establish the level of skill in the art.

41. Specifically, my experience working with industry, undergraduate and

post-graduate students, colleagues from academia, and designers and engineers practicing in industry has allowed me to become directly and personally familiar with the level of skill of individuals and the general state of the art. Taking these factors into consideration, in my opinion, with regard to the ’110 patent, a person of ordinary skill in the art would have a bachelor’s degree in electrical engineering, computer engineering, computer science, or a similar field, along with two years of experience designing or developing wireless networks, including long-term evolution LTE/4G or 5G new radio (NR) cellular technology. Additional education might substitute for some of the experience, and additional substantial experience might substitute for some of the educational background.

42. Based at least on my educational and work experience, I was at least a person of ordinary skill in the art as of the effective filing date of the ’110 patent. And while I note that my qualifications and experiences exceed this definition of a person of ordinary skill of the art, in arriving at the conclusions in this Declaration, I have considered the issues from the perspective of a person of ordinary skill of the art at the relevant time.

43. Unless otherwise stated, I have applied this level of ordinary skill in the art for the purposes of this Declaration.

V. MATERIALS CONSIDERED

44. As part of my independent analysis for this declaration, I have

considered the following: the background knowledge/technologies that were commonly known to persons of ordinary skill in this art during the time before the Critical Date; my own knowledge and experiences gained from my work experience in the field of the '110 patent and related disciplines; and my experience in working with others involved in this field and related disciplines.

45. In addition, I have analyzed the publications and materials listed below. When citing from these references, all emphasis is added unless otherwise noted.

Ex.	Description
APPLE-1001	U.S. Patent No. 11,546,110
APPLE-1002	U.S. Patent No. 11,546,110 File History
APPLE-1004	U.S. Patent Publication No. 2013/0182594 ("Kim")
APPLE-1005	U.S. Patent Publication No. 2015/0195025 ("Kang")
APPLE-1006	U.S. Patent No. 10,944,527 File History
APPLE-1007	4G: LTE/LTE-Advanced for Mobile Broadband, Dahlman, 2014
APPLE-1008	U.S. Patent Publication 2015/0162966 ("Kim-966")
APPLE-1009	P.C.T. Publication No. WO 2017/084235 ("Zhang-235")
APPLE-1010	U.S. Patent Publication No. 2016/0112099 ("Lee")
APPLE-1011	U.S. Patent Publication No. 2019/0387501 ("Park")
APPLE-1012	U.S. Patent Publication No. 2010/0202560 ("Luo")

46. My analysis and conclusions set forth in this declaration are based on the perspective of a POSITA.

VI. TECHNOLOGY BACKGROUND

A. Wireless Network Architecture and Protocols

47. Long Term Evolution (LTE) networks leverage base stations, or eNodeBs (eNBs), to transmit and receive wireless signals when communicating with User Equipment (UEs), such as mobile phones. APPLE-1007, p.13[1], 22. The LTE Radio Access Network (RAN) has a flat architecture where eNBs manage radio-related tasks such as scheduling, radio resource handling, and retransmission protocols. APPLE-1007, p.131. Communication between an eNB and UE involves logical channels, transport channels, and physical channels. Logical channels carry specific types of information that is mapped to transport channels for transmission over the air via physical channels. APPLE-1007, p.136.

48. Multiple-In Multiple-Out (MIMO) architecture uses these techniques by employing multiple transmit and receive antennas. APPLE-1007, pp.89-92. Dahlman's Figure 5.14 shows a simple example of MIMO.

[1] All pagination referenced is to the PDF pagination.

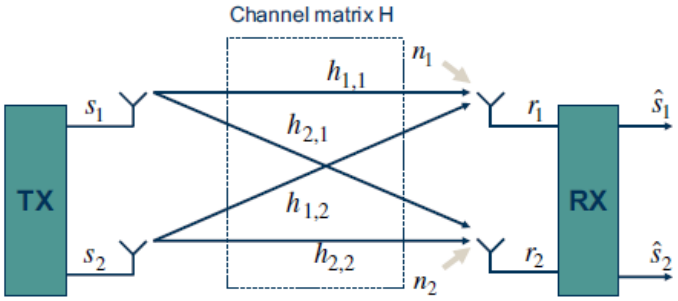


FIGURE 5.14

2 × 2 antenna configuration

APPLE-1007, FIG. 5.14.

49. For downlink (eNB to UE) transmission, LTE can use Orthogonal Frequency Division Multiplexing (OFDM). APPLE-1007, p.37, Chapter 3. OFDM offers more efficient bandwidth by leveraging narrowband subcarriers that are orthogonal, allowing their spectra to overlap without causing inter-subcarrier interference. APPLE-1007, p.40-43. OFDMA (Orthogonal Frequency-Division Multiple Access) extends OFDM to multi-user scenarios by allowing for simultaneous frequency-separated transmissions to and from multiple UEs. APPLE-1007, p.55-59. In the downlink, different subsets of subcarriers can be assigned to different UEs, and similarly in the uplink, different UEs can transmit on different subcarrier subsets. *Id.* An eNB can then dynamically allocate, on a time-frequency basis, its resources to UEs. APPLE-1007, pp.113-116. Dahlman's Figure 3.17 shows examples of multiuser interaction through OFDM schemes.

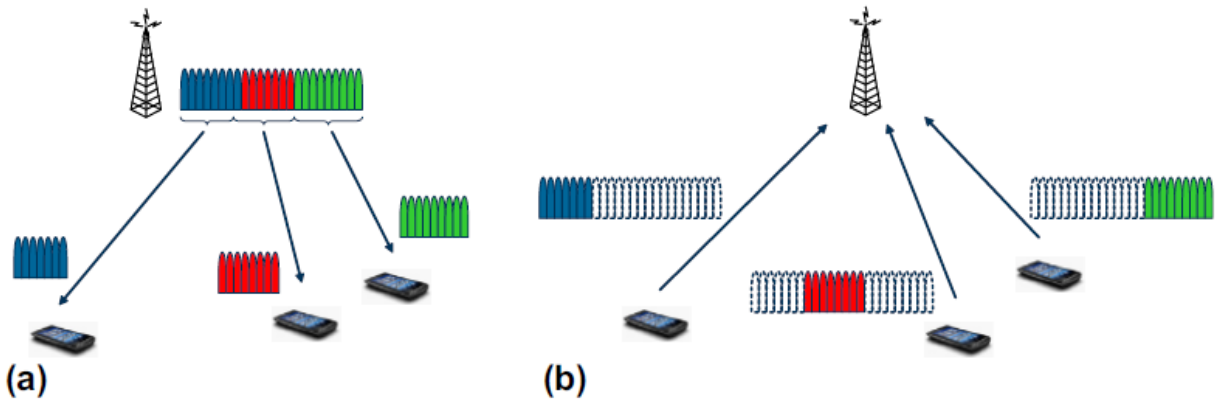


FIGURE 3.17

OFDM as a user-multiplexing/multiple-access scheme: (a) downlink and (b) uplink

APPLE-1007, FIG. 5.14.

50. In such schemes, each eNB transmits reference signals, such as Cell-Specific Reference Signals (CRS) and Channel State Information Reference Signals (CSI-RS), to monitor the network's performance. For example, a UE can use these reference signals to report Channel Quality Indicator (CQI), Precoding Matrix Indicator (PMI), and Rank Indication (RI) back to the eNB. This feedback is collectively known as Channel State Information (CSI). It allows the eNB to perform channel-dependent scheduling. APPLE-1007, pp.154, 185-190.

51. CSI-RS is a component of the LTE downlink, specifically designed to enable UEs to measure the downlink channel characteristics. APPLE-1007, pp.177-182. The eNB configures CSI-RS for each UE, specifying parameters such as periodicity, subframe offset, and the specific resource elements within a

resource block pair used for transmission of data signals and control signaling. APPLE-1007, pp.186-190. Dahlman's Figures 10.8 and 10.13 show example configurations of reference symbols within resource blocks. APPLE-1007, FIG. 10.8 and 10.13. These configurations define the number and structure of CSI-RS used by a UE. APPLE-1007, pp.186-190.

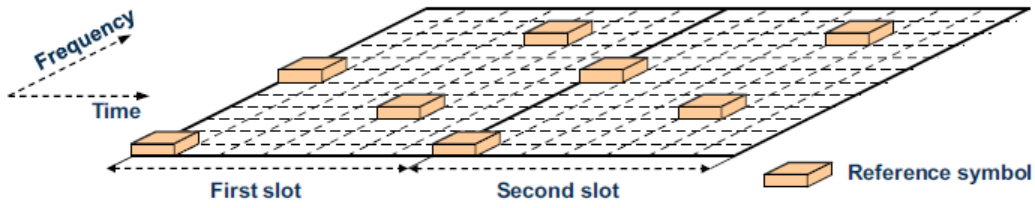


FIGURE 10.8

Structure of cell-specific reference signal within a pair of resource blocks

APPLE-1007, FIG. 10.8.

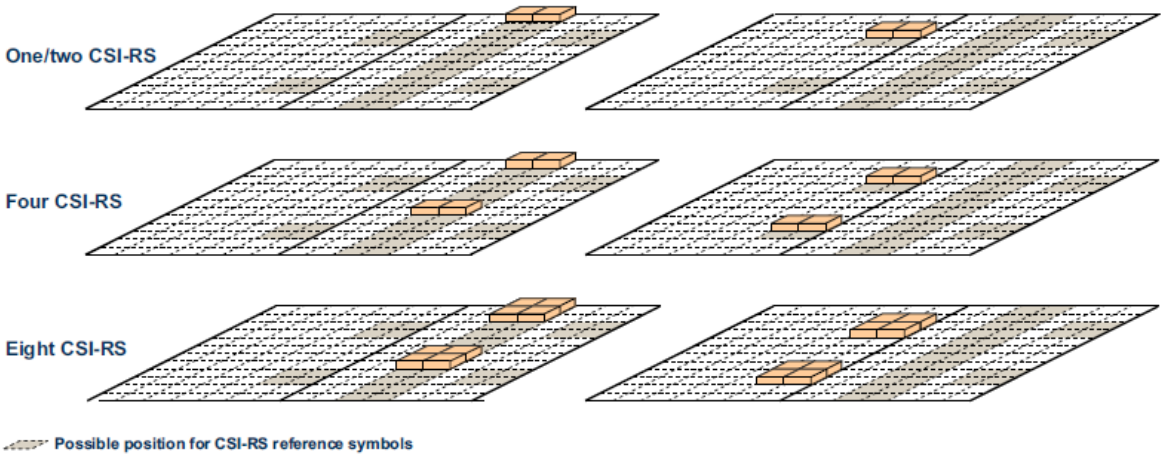


FIGURE 10.13

Examples of reference-signal positions for different number of CSI-RS within a cell. In case of a single CSI-RS, the same structure as for two CSI-RS is used

APPLE-1007, FIG. 10.13.

52. Downlink Control Information (DCI) messages are a mechanism for the eNB to transmit downlink control signaling to the UEs. APPLE-1007, pp.344-350. These DCI messages are carried on the Physical Downlink Control Channel (PDCCH) and the Enhanced Physical Downlink Control Channel (EPDCCH). APPLE-1007, pp.213-219. One PDCCH carries one DCI message. *Id*.

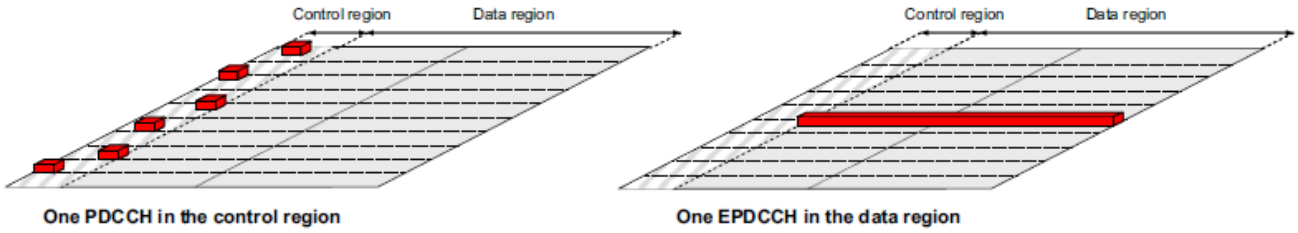


FIGURE 10.29

Principal illustration of PDCCH mapping (left) and EPDCCH mapping (right)

APPLE-1007, FIG. 10.29.

53. Several types of control information (e.g., DCI, MIB, SIB) carry information related to downlink and uplink scheduling assignments, power control commands, and other control information. APPLE-1007, pp.213-219, 355-362. Downlink scheduling assignments inform the UE about the resources allocated for data reception on the Physical Downlink Shared Channel (PDSCH), including details about resource blocks and the modulation and coding scheme (MCS). APPLE-1007, pp.213-219.

54. Different DCI formats support different transmission modes and scenarios, and some formats include a field for a Sounding Reference Signal (SRS) request, which can be used to trigger uplink transmissions that aid in channel estimation, and a Downlink Assignment Index (DAI) for Time Division Duplexing (TDD) systems. APPLE-1007, pp.229-239. The specific DCI format used depends on factors such as the cell bandwidth, the number of transmit antennas, and whether cross-carrier scheduling is configured. APPLE-1007, pp.213-219.

55. The interaction between CSI-RS and DCI messages is used for the LTE system to operate efficiently. APPLE-1007, pp.185-189, 355-362. For example, a UE's measurements of CSI-RS provide the eNB with information about the downlink channel quality. APPLE-1007, pp.185-189. Based on the reported CSI (CQI, PMI, RI) transmitted in response to the CSI-RS, the eNB can then make informed decisions regarding scheduling and link adaptation (selecting the appropriate modulation and coding scheme). APPLE-1007, pp.341-350. The eNB, in turn, then communicates these scheduling decisions and transmission parameters back to the UE through downlink scheduling assignments within DCI messages. APPLE-1007, pp.229-234. Furthermore, the eNB can dynamically trigger the eNB to obtain up-to-date channel information on demand. APPLE-1007, pp.291-294. The DCI messages, therefore, act as the communication channel through which the eNB conveys the transmission configurations, often optimized based on the

channel information gleaned from the CSI reports that are derived from CSI-RS measurements. APPLE-1007, pp.213-219.

56. In LTE, the physical structure for transmitting information such as CSI-RS and DCI is organized within a time-frequency grid. APPLE-1007, pp.148-154. As shown in Dahlman's figures below, the fundamental unit in the time domain is the frame. Each frame has a duration of 10 milliseconds and is composed of ten 1 millisecond subframes, with each subframe having two slots. *Id*. In the frequency domain, the system bandwidth is divided into subcarriers, and these, along with the OFDM symbols in the time domain, form the smallest physical resource unit known as a resource element. *Id*. Different time resources or subframes are assigned to UEs for either uplink (transmission) or downlink (receipt). APPLE-1007, 157-160, 355-362, FIG. 9.7. The time resources can assign windows of time for uplink or downlink (e.g., a Time Division Duplexing scheme). *Id*.

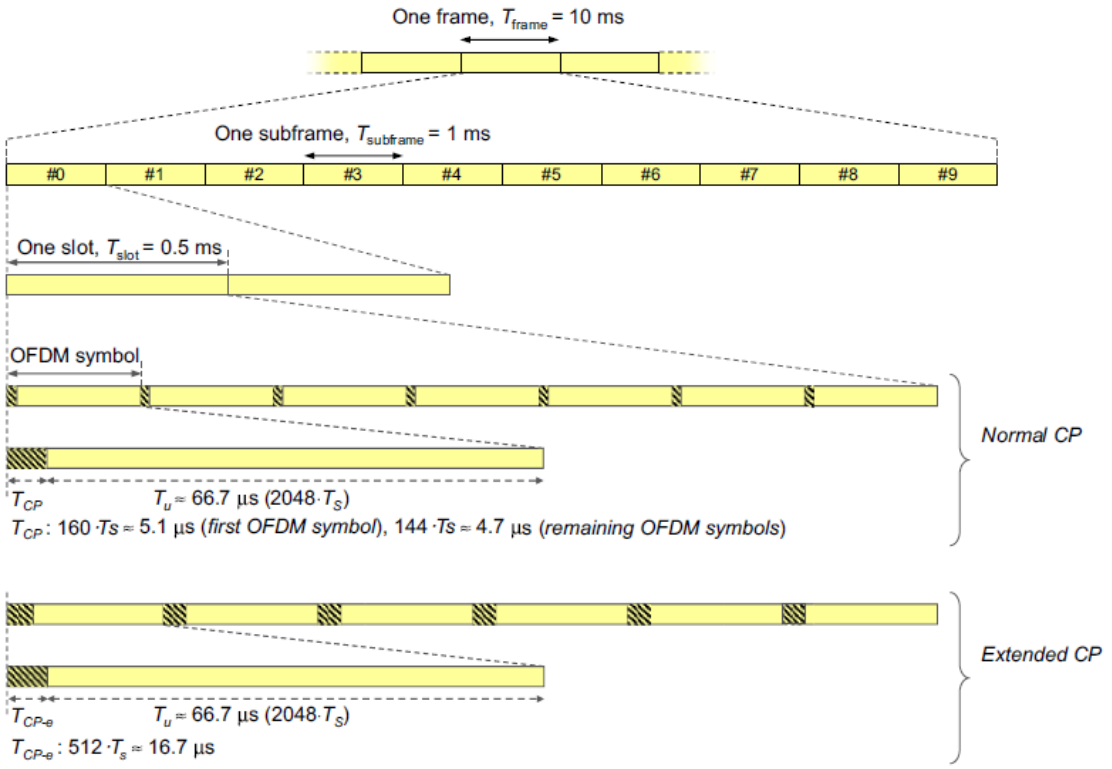


FIGURE 9.1

LTE time-domain structure

APPLE-1007, FIG 9.1.

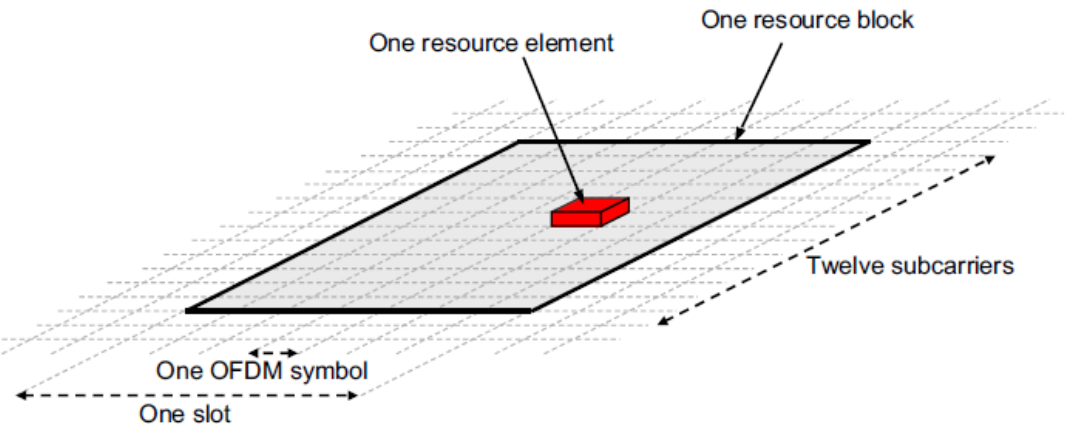


FIGURE 9.2

The LTE physical time-frequency resource

APPLE-1007, FIG. 9.2.

B. Antenna Systems on a UE

57. As noted above, a UE with a MIMO architecture leverages multiple antennas. A UE can use antenna ports, which are logical ports distinct from physical antennas. APPLE-1007, pp.154-155 ("[A]n antenna port is an abstract concept that does not necessarily correspond to a specific physical antenna"). A UE uses antenna ports to generally relate to signal types rather than physical antennas. APPLE-1007, pp.154-155. For example, in practice each of these antenna ports can correspond to a specific reference signal (e.g., CSI-RS to antenna ports 15-22). *Id*. With this relationship between signals (CSI-RS) and antenna ports (15-22), the "reference signal can be used to estimate the channel corresponding to the specific antenna port." *Id*.

58. Antenna ports enable the UE to understand the characteristics of the radio channels experienced by different downlink transmissions. *Id*. Specifically, a UE can assume that two transmitted signals have experienced the same radio channel if they are transmitted from the same antenna port. *Id*. This understanding informs several physical layer procedures like channel estimation using CSI-RS.

59. Other forms of control information serving to coordinate transmission is a Master Information Block (MIB) and System Information Block (SIB). APPLE-1007, pp.355-362. These types of signaling are used to convey cell system

information to UEs. APPLE-1007, pp.355-362. The cell system information is "repeatedly broadcast by the network and [] needs to be acquired by terminals [UEs] in order for them to be able to access and, in general, operate properly within the network and within a specific cell. The system information includes, among other things, information about the downlink and uplink cell bandwidths, the uplink/downlink configuration in the case of TDD, detailed parameters related to random-access transmission, etc." APPLE-1007, pp.355-362.

VII. THE '110 PATENT

A. Overview of the '110 Patent

60. The '110 patent is directed to Multiple-Input Multiple-Output (MIMO) systems and "a method and device for multi-antenna transmission" within these MIMO systems. APPLE-1001, Abstract. According to the '110 patent, a large amount of signaling overhead is required to service multiple users within a single cell. APPLE-1001, 1:39-46("[S]ignaling overhead of wireless resource dynamic scheduling is an urgent problem to be solved in massive MIMO system[s]."). The '110 Patent proposes using a series of CSI-RS for scheduling more efficient communication between a base station and user equipment (UE) in a MIMO system, but these methods were already employed by the prior art.

61. The '110 patent purports to solve efficiency problems by associating a time resource pool with an antenna port group, enabling a UE to quickly determine

the location of the corresponding time resource pool and the antenna virtualization vectors used for receiving signals on the time resource pool. *Id.*, 1:39-2:17. Figure 9 illustrates how a different time resource pool is assigned to each antenna port group for transmitting signals. *Id.*, 17:1-11; FIG. 9. But the assignment of antenna ports within particular resource elements or time slots was well known.

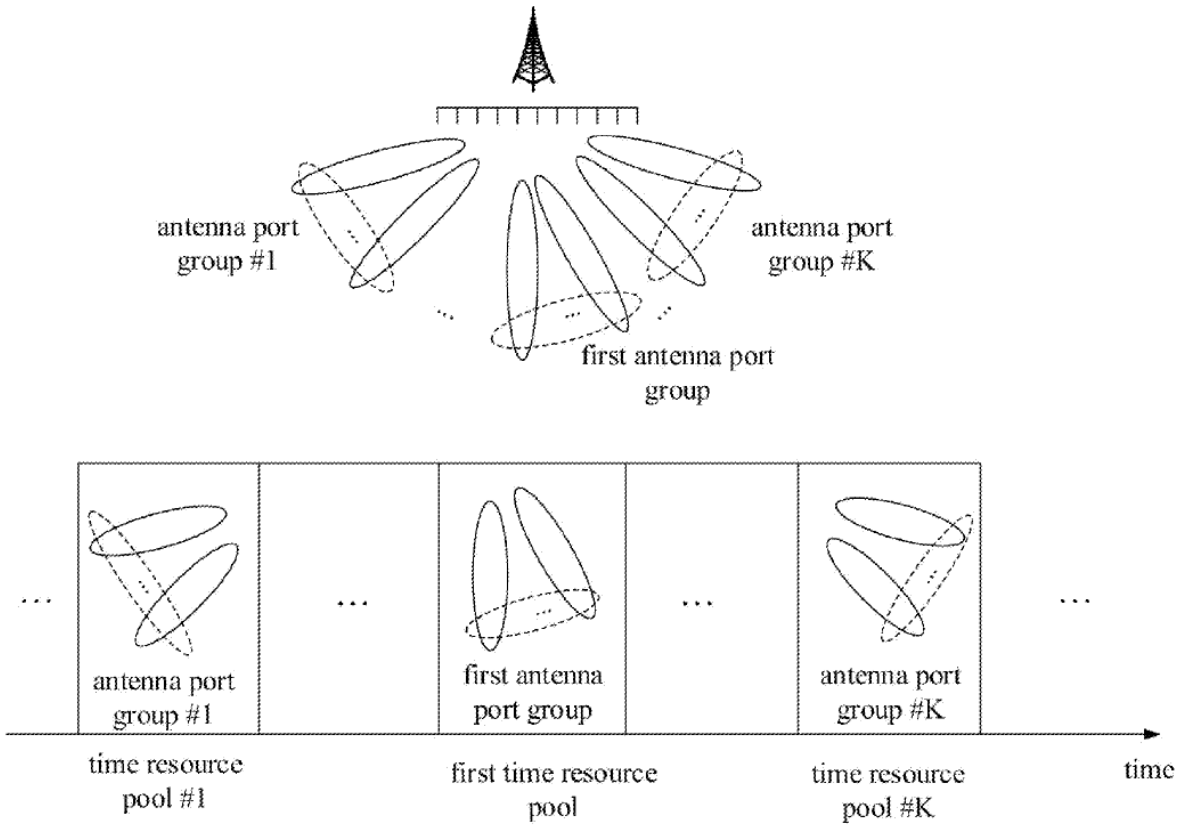


Fig. 9

APPLE-1001, FIG. 9.

62. When transmitting with multiple antenna ports within an antenna port group, the ’110 patent also describes using an antenna virtualization vector to map the physical antennas to the antenna port(s). *Id.*, 2:5-44. For example, the ’110

patent describes the base station using a first antenna virtualization vector for transmission, and the UE using a second antenna virtualization vector for receiving the transmission. *Id.*, 4:55-67, 18:42-63, 20:4-13. These concepts, however, were already taught by the prior art applied here.

B. Prosecution History of the '110 Patent

63. The cover of the patent and Counsel has informed me that U.S. Patent No. 11,546,110 issued on January 3, 2023 from U.S. Patent Application No. 17/143,180 ("the '180 application"), which was filed on January 7, 2021 with 20 claims. *See* APPLE-1002. Counsel informed me that a rejection was issued on the grounds of §112(b) and Double Patenting. APPLE-1002, 59-61, 76-82. Counsel further explained that after the filing of a terminal disclaimer, amendments to address the §112(b) rejection, and an examiner interview, a notice of allowance was issued. APPLE-1002, 16, 73.

VIII. OVERVIEW AND COMBINATIONS OF PRIOR ART REFERENCES

A. Overview of Kim

64. Analogous to the '110 patent, Kim discloses a MIMO system where a base station transmits signals, such as data and reference signals, through multiple antenna port groups to UEs with a goal to minimize overhead. *Compare* APPLE-1004, 0002-0010, 0016-0017, 0049-0050, 0055, with APPLE-1001, 1:20-22, 1:24-46, 2:28-36. Kim describes that a UE receives the control signaling to coordinate

the receipt of reference signals (e.g., CSI-RS) used to measure channel state (e.g., the quality of a channel) and eventually improve channel quality. APPLE-1004, 0007, 0051-0052. In particular, Kim contemplates improvements upon the 3GPP LTE framework introduced with respect to FIGS. 1 and 2. All of the Kim's disclosures are related and informative of both this background and incremental improvements disclosed by Kim.

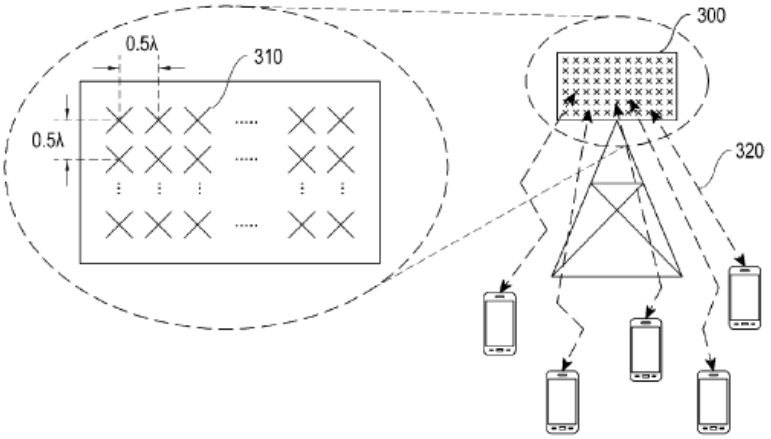


FIG.3

APPLE-1004, FIG. 3.

65. Kim discloses that the base station (eNB) transmits reference signals, such as CSI-RS, using groups of antennas commonly found in MIMO systems. APPLE-1004, 0080-0081. For example, as shown below, Kim discloses grouping multiple physical antennas into five groups, where each group has eight antennas.

APPLE-1004, 0082-0083. Each group transmits signals within time resources, e.g., at different subframes represented across the x-axis. APPLE-1004, 0060-0061, 0082-0083.

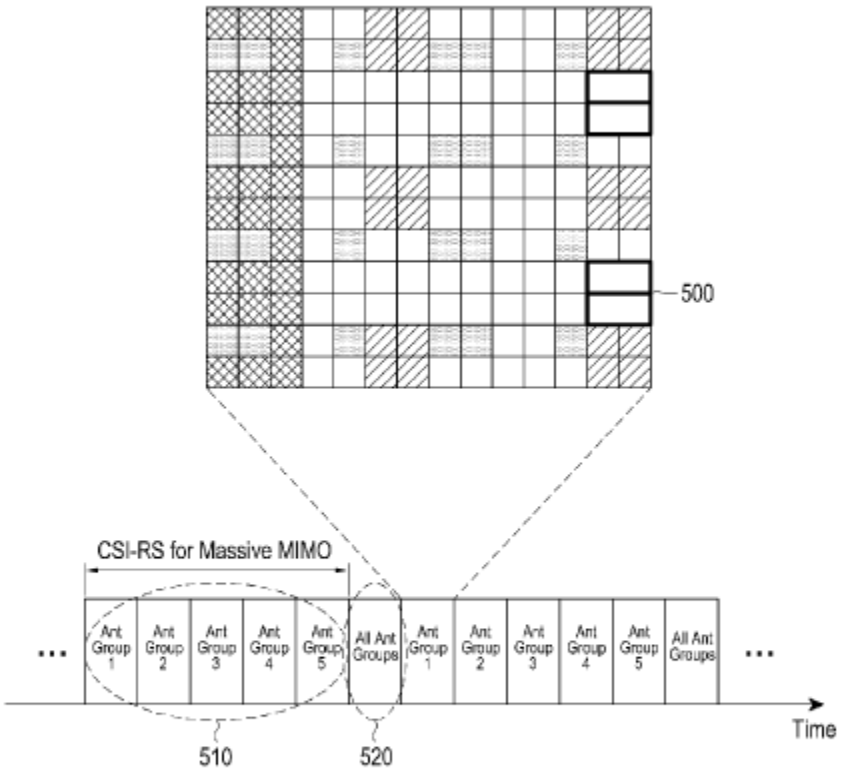


FIG.5

APPLE-1004, FIG. 5.

66. Kim teaches the use of control information signaling used in receiving CSI-RS signals. Specifically, Kim discloses that "an eNB should notify a UE of related control information before transmitting a CSI-RS" and that "[t]he control information is imperative for proper reception of the CSI-RSs for massive MIMO

and proper determination of the channel state based on the received CSI-RSs by the UE." APPLE-1004, 0065. Kim seeks to improve coordination between a base station and a UE through use of various techniques including channel reference signals, control information, scheduling, and antenna port coordination.

67. Kim also teaches the use of CSI-RS antenna port CDM groups. APPLE-1004, 0051-0052, 0060, 0088, 0096. Kim demonstrates an example of using four antenna ports to send a CSI-RS in FIG. 2. APPLE-1004, 0010-0014, FIG. 2.

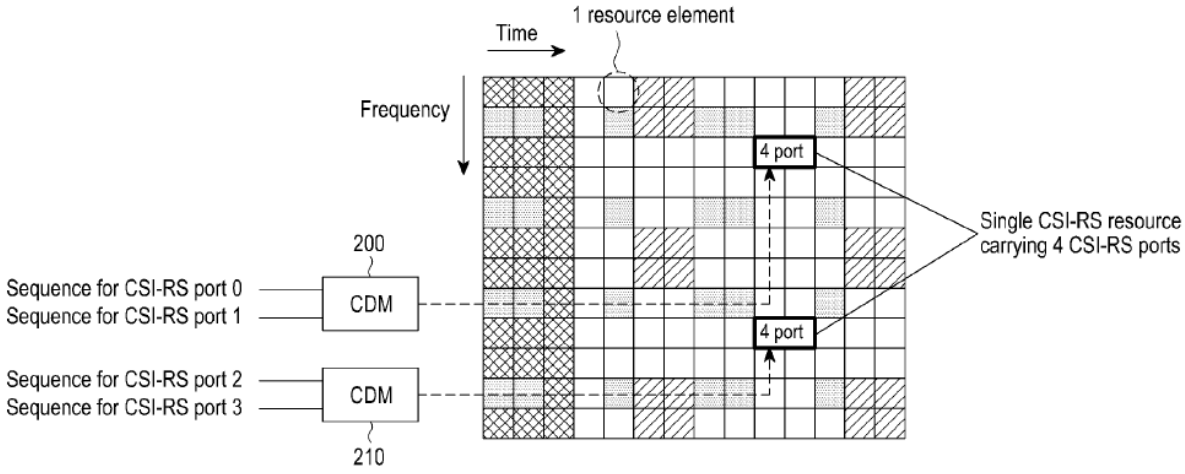


FIG.2
(RELATED ART)

APPLE-1004, FIG. 2.

B. Overview of Dahlman

68. Dahlman is a textbook covering wireless networks including 4G LTE/LTE-Advanced and is analogous to the '110 Patent. This reference was not

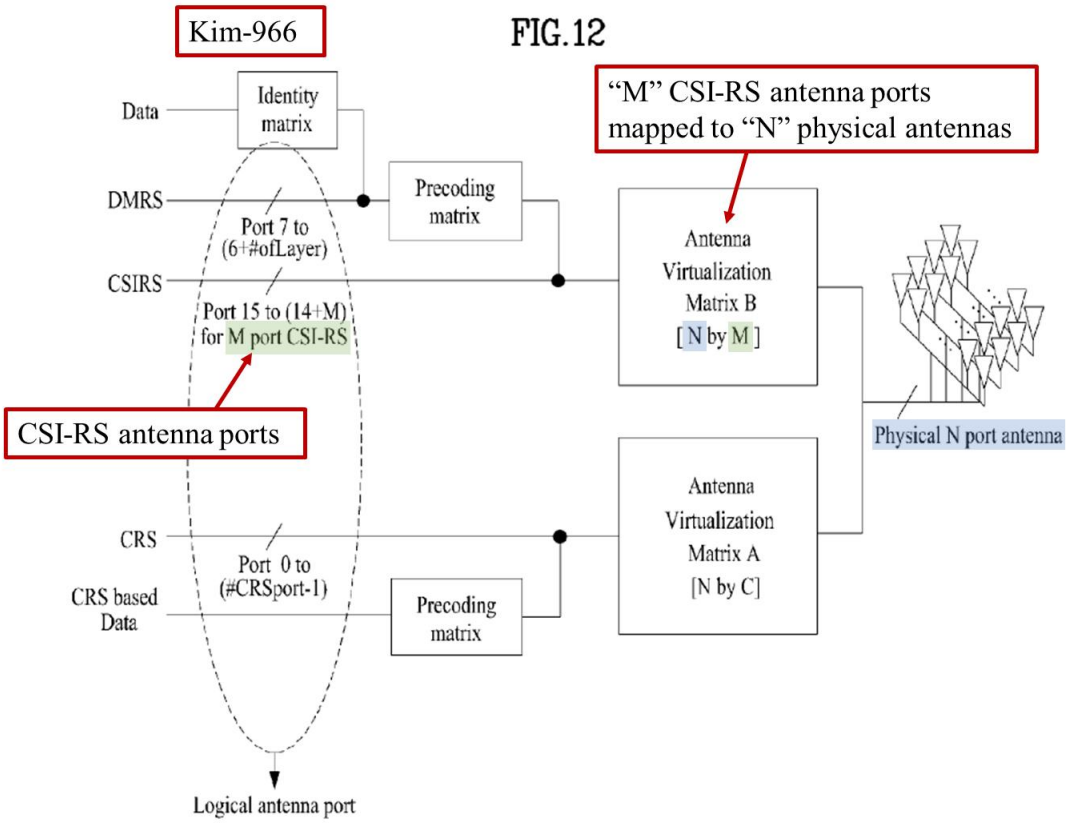
only published prior to the Critical Date, but would have been known to a POSITA as teaching the various protocols, configurations, capabilities, and organization of the types of networks disclosed in the ’110 Patent as well as Kim. An overview of Dahlman’s teachings is presented in the Technology Background section.

C. Overview of Kim-966

69. Kim-966 describes the use of antenna virtualization to map between antenna ports and physical antennas. Particularly, Kim-966 addresses the challenges of downlink channel estimation (e.g., CSI-RS) in wireless MIMO communication systems, utilizing numerous transmission antennas. APPLE-1008, FIG. 22, 0090, 0207-0215. Kim-966 describes techniques to mitigate the substantial overhead associated with transmitting Channel State Information Reference Signals (CSI-RS). APPLE-1008, 0003-0004, 0019(“overhead may be reduced and a larger number of channel state information-reference signals (CSI-RSs) may be transmitted.”), 0087. One such approach involves the transmission of CSI-RS for a limited number of antenna ports (M) out of a larger set of available physical antenna (N), where M is less than or equal to N. APPLE-1008, 0135-0136, 0141.

70. Central to Kim-966’s approach, is the utilization of an antenna virtualization matrix, specifically denoted as matrix B. APPLE-1008, 0135-0136. This matrix B, characterized by dimensions of N by M, is employed for CSI-RS

transmission. *Id*. It serves the purpose of mapping CSI-RS originating from M logical antenna ports to N physical antennas. APPLE-1008, 0135-0136, 0141, FIG. 12. The matrix B conceptually illustrates this process of antenna virtualization. APPLE-1008, 0134-0136. As an example of this mapping, figure 12 depicts antenna port to physical antenna element mapping. APPLE-1008, FIG. 12.



APPLE-1008, FIG. 12.

71. The antenna virtualization matrix B contains a collection of vectors that facilitate this mapping. APPLE-1008, 0134-0136, 0141. A POSITA would have understood and found obvious that a matrix would include one or more

vectors. APPLE-1007, p.196(a "matrix W is a vector of size $N_A \times 1$"). The signal for the CSI-RS antenna ports is represented by a matrix X, the signal resulting from antenna virtualization is represented as $Z = BX$, where Z corresponds to a matrix of vectors and z_i corresponds to the i-th CSI-RS antenna port. APPLE-1008, 0136, 0141. This signifies that the vectors within matrix B are applied to the signals associated with the M logical CSI-RS ports, transforming them into signals that are then transmitted over the physical antennas. APPLE-1008, 0134-0136. The teaching demonstrates a relationship between the logical CSI-RS antenna ports, the vectors in the antenna virtualization matrix, and the physical antennas elements used for transmission.

D. Combination of Kim, Dahlman, and Kim-966

72. Kim contemplates leveraging a MIMO system "for transmitting a reference signal for effective data transmission and reception, measuring interference, and generating channel state information." APPLE-1004, 0016. Kim's system utilizes CSI (e.g., CSI-RS, CIS reports) and control information transmitted between a base station and a UE for the purposes of improving the communication channel characteristics, and thus, improving channel throughput. APPLE-1004, 0019, FIG. 9 and 12.

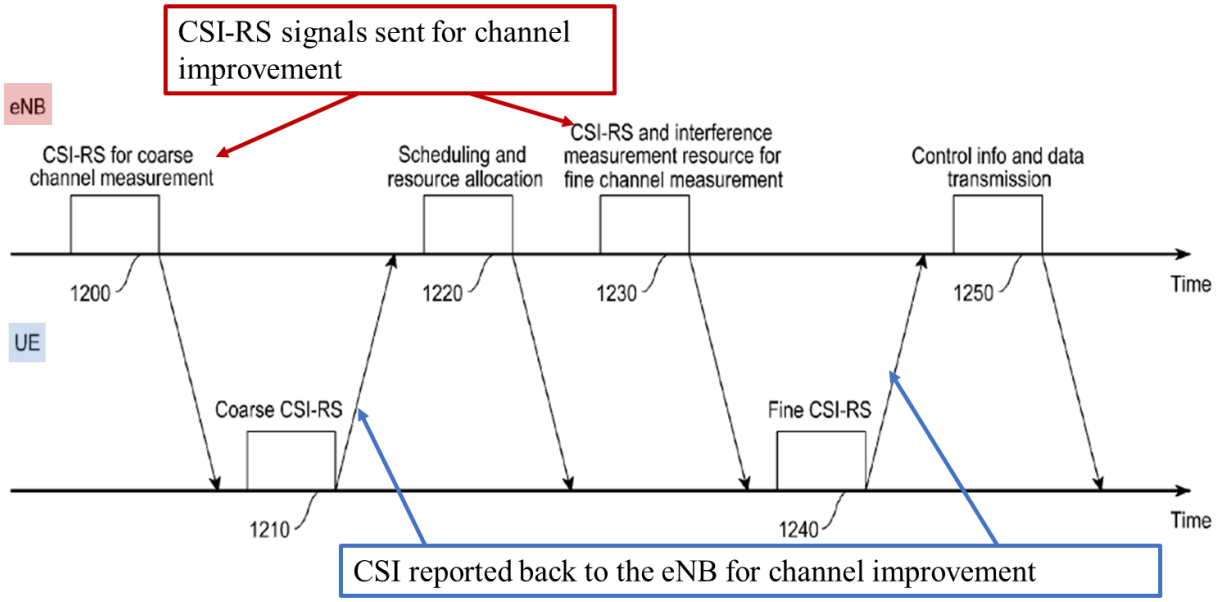


FIG.12

APPLE-1004, FIG. 12.

73. Specifically, Kim discloses use of "a plurality of antenna groups, transmitting the reference signal (e.g., CSI-RS) to UEs in different time intervals or frequency intervals according to the antenna groups." APPLE-1004, 0022. With "control information," Kim coordinates the generation of signals using virtual antenna ports. APPLE-1004, 0009-0014, 0020-0021. In complementary fashion, Kim-966 also coordinates transmission from a "plurality of antennas" in coordination with antenna ports (e.g., CSI-RS antenna ports) through the use of "antenna virtualization matrix[es]." APPLE-1008, 0086-0087, Table 3, 0134-0136; 0207-0215.

Kim

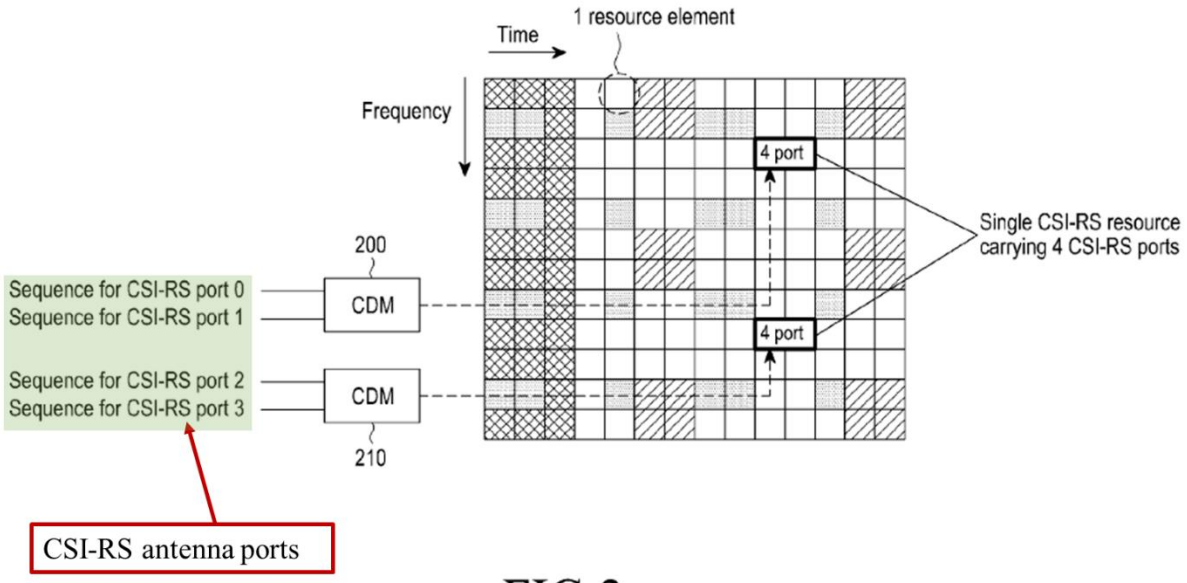
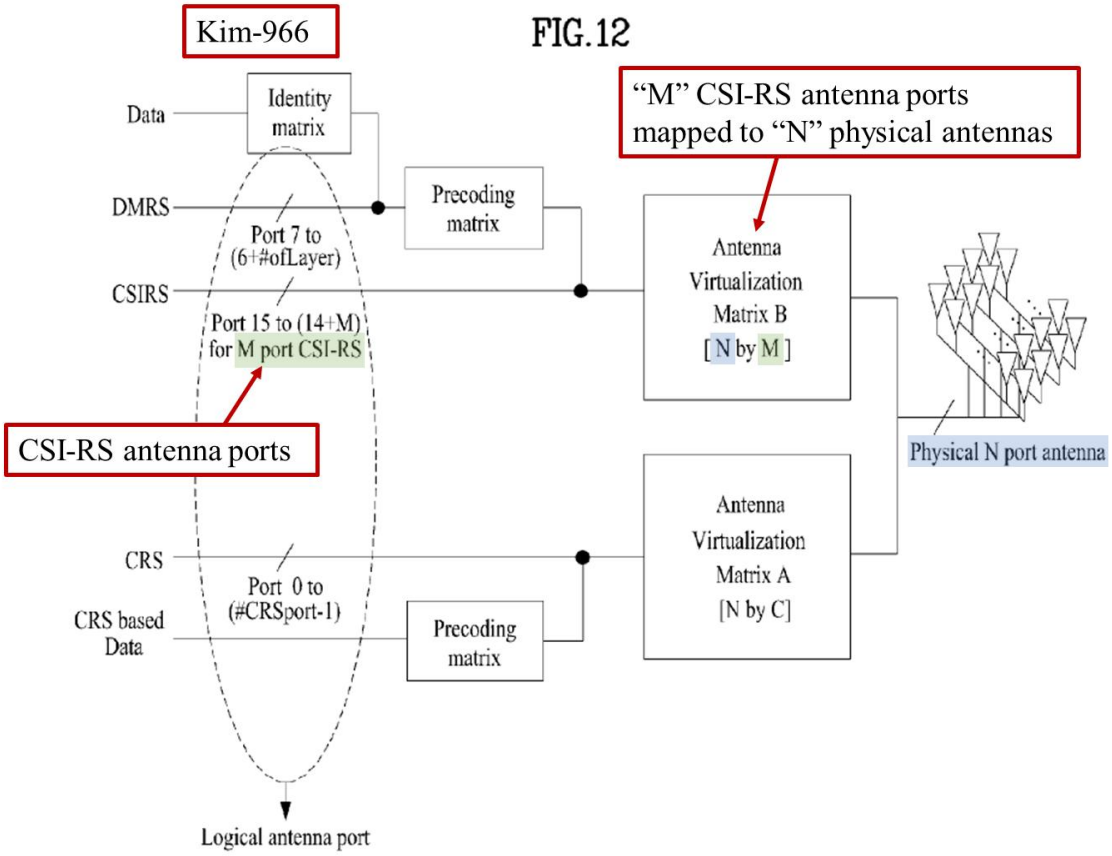


FIG.2
(RELATED ART)

APPLE-1004, FIG. 2



APPLE-1008, FIG. 12.

74. Further, as demonstrated in each reference's overview, both Kim and Kim-966 envision operability within known and compatible standards as described by Dahlman—demonstrating that Kim, Dahlman, and Kim-966 clearly operate within the same space. APPLE-1004, 0005-0006; APPLE-1008, 0002, 0042, 0046; *see generally* APPLE-1007; *see* §VI (providing an overview of the LTE-Advanced architecture, including the use of reference signals like CSI-RS for CSI acquisition, the use of control information for resource allocation, and the

fundamental time-domain structure of LTE). More specifically, all references describe enabling communications (e.g., CSI-RS) between a base station and UE using multiple antennas in a MIMO architecture. APPLE-1004, 0002-0008; APPLE-1008, 0002, 0042, 0046.

75. A POSITA would have found it obvious to combine the concepts related to CSI-RS transmission, CSI reports, and antenna virtualization from Kim and Kim-966 within the analogous framework described in Dahlman. For example, a POSITA seeking to implement or improve the Kim and Kim-966's teachings within the LTE structure would naturally consult a resource like Dahlman that provides an overview of standardized practices and consider how Kim and Kim-966's techniques fit within the established system architecture elaborated on in Dahlman.

76. Specifically, a POSITA reviewing Kim's disclosure of transmitting CSI-RS using antenna port groups, would look to Kim-966 for implementation details regarding the use of an antenna virtualization matrix of vectors to coordinate mapping from Kim's CSI-RS antenna ports to physical antenna elements. Similarly, because of the similar infrastructure used between Kim and Kim-966, a POSITA would have had a reasonable expectation of success in relying on Kim-966 for disclosure of the antenna virtualization matrix that would be used to realize the antenna ports contemplated by Kim.

77. A POSITA implementing any of the individual mechanisms described through the Combination would have predictably sought to implement these mechanisms within the knowledge of a POSITA such as those defined by the existing LTE structure described in Dahlman. The combination would yield the anticipated success of enabling or enhancing the teachings of Kim and Kim-966 regarding channel estimation, resource coordination, antenna virtualization, and channel efficiency within the known techniques and existing LTE-Advanced architecture. *See* VI, VIII.A-C. Such implementation would have been accomplished using existing knowledge held by a POSITA and without requiring inventive genius beyond the ordinary skill in the art. The fact that the Combination operates within the well-established LTE-Advanced framework detailed by Dahlman—a resource representative of "the background knowledge possessed by" a POSITA—provides a strong motivation for their combination.

78. Finally, Counsel informs me that the law reinforces that a motivation to combine prior art references must exist and cannot simply be based on the fact that the elements were known. In this scenario, the motivation stems from the functional relationship between reference signal transmission/reception (Kim) and the underlying communication system's antenna virtualization resources (Kim-966), as part of LTE-Advanced architecture described in Dahlman. A POSITA aiming to utilize the techniques in the Combination would necessarily need to

implement them within the LTE structure described by Kim, Dahlman, and Kim-966. The Dahlman textbook itself discusses various reference signal configurations and their placement within subframes, providing an explicit suggestion or motivation to reference Dahlman when implementing the Combination. Therefore, the combination is not arbitrary but driven by the functional necessity of implementing the Combination within the standard architecture described throughout Dahlman, leading to a predictable and beneficial outcome for channel state estimation, resource allocation, and system performance.

79. Given the disclosures of Kim, Dahlman, and Kim-966, a POSITA would have been motivated to combine them—and found such a combination obvious for the following reasons:

80. First, a POSITA would have recognized Kim's MIMO system, which has "scores or more" antennas, would benefit from Kim-966's antenna virtualization matrix of vectors, given the noted efficiency improvements available through virtualization relating to managing antenna ports and physical antennas. APPLE-1004, 0016-0024; APPLE-1008, 0134-0136, 0141. Applying Kim-966's concepts to Kim would thus offer a predictable approach to handling Kim's plurality of antenna ports in a multi-antenna MIMO system. The concept of antenna virtualization was known in MIMO systems and served the purpose of mapping the defined antenna ports to the physical antenna elements. APPLE-1007,

273. A POSITA would have understood and found obvious that this combination would have been accomplished with known elements according to known methods (e.g., control information such as MIB, SIB and CSI-RS) to achieve predictable results. Not only would the methods be predictable because of known techniques described throughout the Petition, but it would have been obvious to implement Kim-966's MIMO LTE compliant methods with Kim's similar MIMO LTE system utilizing the existing elements provided through the LTE standards described in Dahlman.

81. Second, Kim recognizes the challenge of precisely measuring channel state information (CSI) in MIMO, and Kim highlights that these challenges are a consequence of multiple antennas and UEs. APPLE-1004, 0051. With respect to MIMO systems that also have multiple antennas and UEs, Kim-966 describes measuring CSI and improving channel characteristics through CSI reports. APPLE-1008, 0005, 0017. And, Kim-966 would have told a POSITA to use the antenna virtualization matrix of vectors contemplated to coordinate the antenna port groups taught by Kim and Kim-966 with the plurality of transmission antennas used in MIMO. APPLE-1004, 0051, 0060; APPLE-1008, 0136, 0207-0218, FIG. 12, 22. Indeed, Dahlman corroborates this point by demonstrating an example of "antenna virtualization . . . used.to map the two-antenna-port signal to four physical antennas." APPLE-1007, 273. A POSITA would have readily

appreciated the applicability of Kim-966's methods, which employ channel and antenna coordination through shared control information (e.g., antenna virtualization vectors) to improve the adaptability of each channel and thus improve channel and system throughput. APPLE-1008, 0136, 0141. Further, a POSITA would have understood that such antenna virtualization is used so that base stations and UEs can operate agnostic to the number of physical antenna elements available..

82. Specifically, Kim-966 describes determined and coordinated patterns of antenna virtualization based on very antennas used in transmission. APPLE-1004, 0018, 0051; APPLE-1008, 0136. Kim-966's coordination of antenna virtualization occurs through transmitting, to the UE, control information with respect to an antenna virtualization pattern of the UE. APPLE-1008, 0086-0087, Table 3, 0136.

83. A POSITA would have recognized the use of antenna virtualization described in Kim-966, for the plurality of mobile UEs described in Kim and Kim-966, as a known technique, compatible with the existing structure of Kim, to achieve the results of improving MIMO systems described in Kim, especially when considering the well-known nature of the increasing number and mobility of UEs around the Critical Date. Thus, a POSITA would have advantageously leveraged the antenna virtualization matrix of Kim-966 into Kim's antenna port

groups through known techniques of the 3G/LTE architecture (e.g., control information to coordinate communication). For example, Kim-966 teaches that the "antenna virtualization matrix B . . . designated/configured for each UE" by control information. APPLE-1008, 0136, 0086-0087, Table 3. In addition, Kim already disclosed the use of both antenna ports for designated purposes (e.g., CSI-RS) and the use of control information for the coordination of transmissions. APPLE-1004, 0062-0078, 0098-0108, 0119-0126; APPLE-1008, 0083, 0086-0087, Table 3, 0134-0136. Finally, Dahlman corroborates these teachings with details on such control information such as MIB and SIB communication to designate resource allocation. APPLE-1007, pp.355-362. Thus, a POSITA would have had a reasonable expectation of success to include Kim-966's determination of and coordination of antenna virtualization matrixes with Kim's CSI-RS antenna ports into Dahlman's already existing architecture that includes control information for coordination of such transmissions.

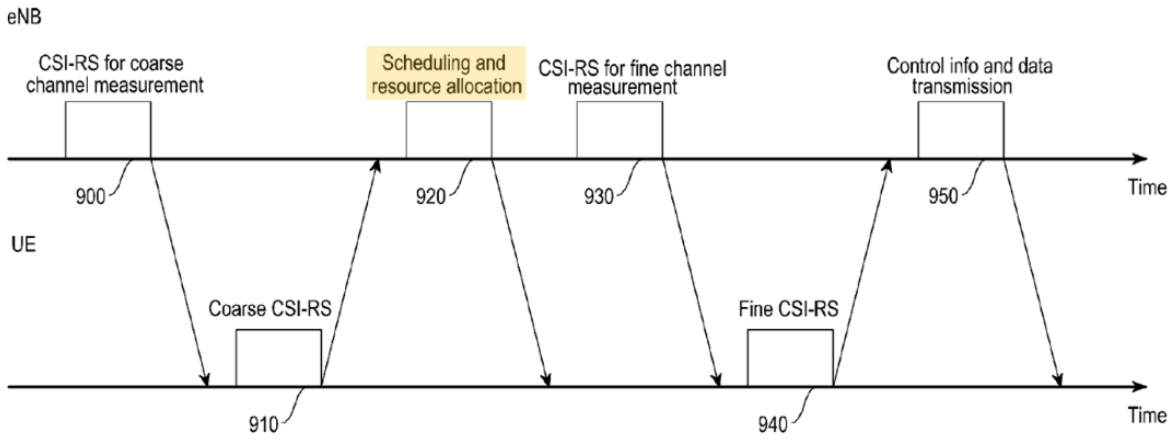


FIG.9

APPLE-1004, FIG. 9.

84. The Combination would have provided a MIMO system that includes a base station and UE, communicating through various physical antenna and conceptual antenna ports using antenna virtualization vectors. APPLE-1004, 0009-0013; APPLE-1008, 0086-0087, 0136. The communication across the multiple antennas would have been coordinated through Kim and Dahlman's control information, augmented with Kim-966's antenna virtualization vectors. APPLE-1004, 0018-0020, 0065-0078; APPLE-1008, 0084-0087, 0136. By the Critical Date, the concept of using control information to coordinate communication was taught and known in 3G/LTE standards as demonstrated by Dahlman, Kim, and Kim-966. APPLE-1007, 213-119, 157-160.

85. Third, Kim and Kim-966 describe methods of dividing transmission

antennas into groups to transmit CSI-RS within limited resources. APPLE-1004, 0055-0058; APPLE-1008, 0019, 0077, 0078. A POSITA with knowledge of the techniques described in Kim-966 for antenna virtualization matrix, which applies antenna virtualization vectors to antenna port groups (pairs of CSI-RS antenna ports), would have viewed this as an alternative or complementary technique for resource management, and thus consider it obvious to apply Kim-966's antenna virtualization vector with Kim's antenna port groups to manage CSI-RS transmissions for a large number of Kim's antennas and antenna ports. APPLE-1008, 0084-0086.

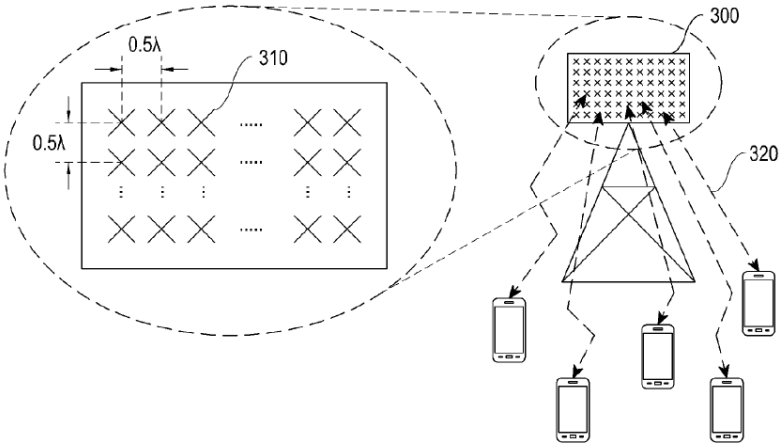
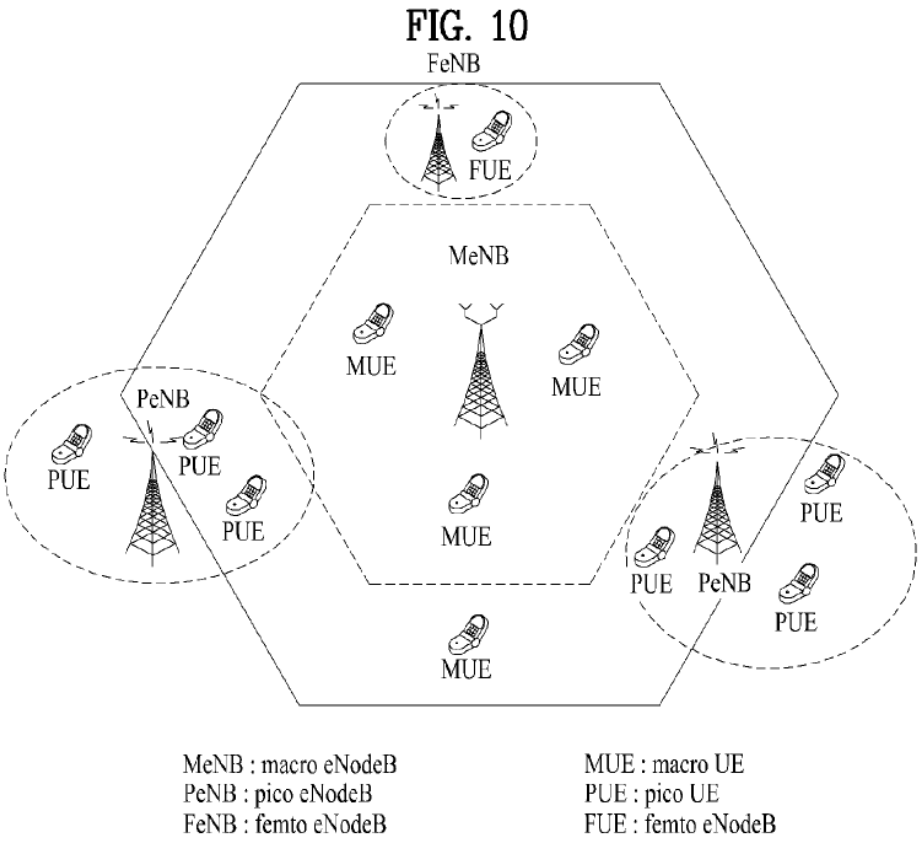


FIG.3

APPLE-1004, FIG. 3.



APPLE-1008, FIG. 10.

86. Fourth, Kim stresses the importance of backwards compatibility. APPLE-1004, 0054. Kim-966 teaches that the antenna virtualization vectors can be scaled to account for different numbers of available antenna ports and varying physical antenna array sizes. APPLE-1008, 0084-0087, 0136, FIG. 125, 0096. A POSITA would have recognized that using antenna virtualization taught in Kim-966 was, at the Critical Date, a known technique to efficiently manage transmissions using various physical antenna array sizes, ensuring backwards

compatibility. APPLE-1004, 0005-0006, 0054; APPLE-1008, 0084-0087, FIG. 12. As such, POSITA would have readily recognized that that combining Kim and Kim-966 in the architecture corroborated by Dahlman would address a known problem in the field—backwards compatibility.

87. Fifth, both Kim and Kim-966 are within the field of wireless communication systems, specifically dealing with multiple antenna techniques. APPLE-1004, 0001-0008; APPLE-1008, 0207-0218, FIG. 12, 22. Kim addresses the specifics of CSI-RS in MIMO, and Kim-966 provides general methods for antenna virtualization in MIMO systems. *Id*. Dahlman corroborates the well-established MIMO architecture by describing the same CSI-RS transmissions using multiple antenna ports and physical antennas. APPLE-1007, pp.186-188, Chapter 5. A POSITA would have naturally looked to interrelated teachings within this field. Recognizing that Kim-966's virtualization aims to improve MIMO efficiency and flexibility, a POSITA would have been motivated to combine Kim-966's teachings into Kim, particularly in managing a large number of antenna ports.

88. Sixth, at the time of the Critical Date, there was a trend towards MIMO systems aimed to increase network capacity and user throughput. APPLE-1004, 0005-0008; APPLE-1008, 0019-0020. There was a clear market demand and incentive for efficient and scalable methods to manage these complex systems. A POSITA would have been motivated to combine the CSI-RS framework of Kim

with the virtualization techniques of Kim-966 in the MIMO systems outlined in Dahlman to develop more efficient and scalable MIMO systems that meet the demands for higher capacity without overwhelming signal overhead. APPLE-1004, 0008, 0014, 0097, APPLE-1008, FIG. 22.

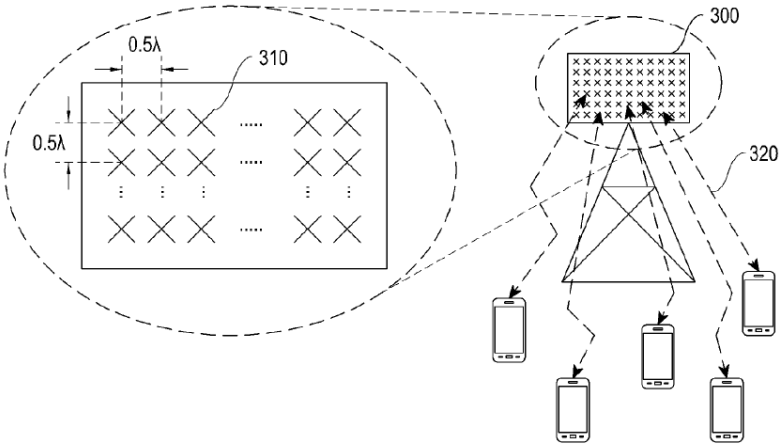
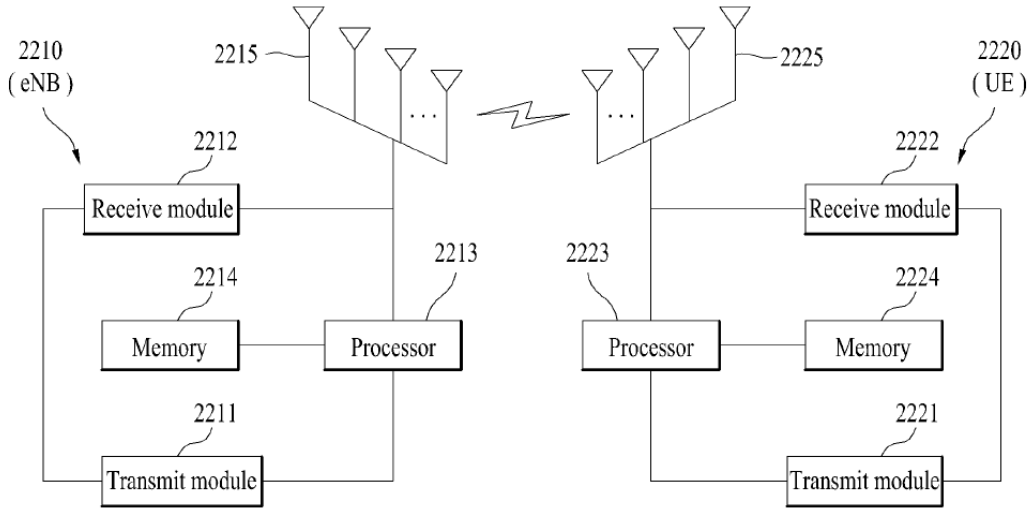


FIG.3

APPLE-1004, FIG. 3.

FIG. 22



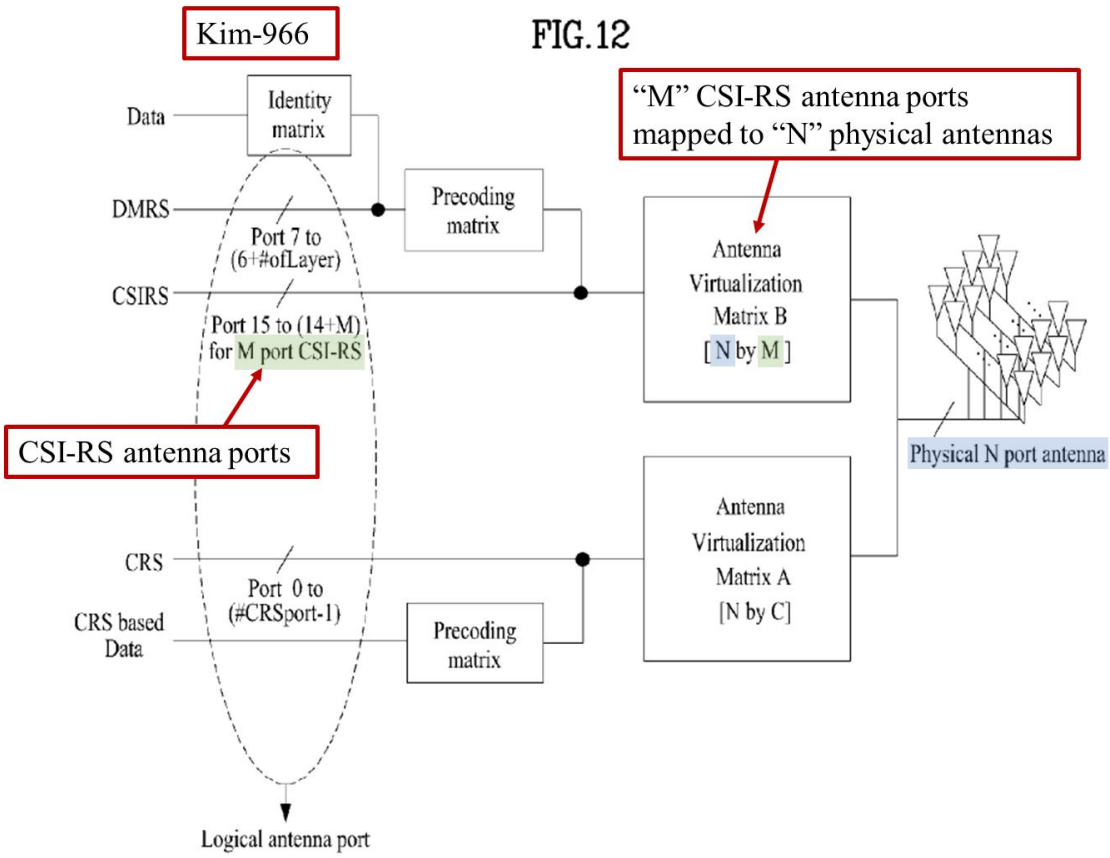
APPLE-1008, FIG. 22.

89. As discussed above, the Combination would have involved incorporating prior art elements according to known methods to yield predictable results. Each of Kim's CSI-RS antenna ports and Kim-966's antenna virtualization matrix, and Dahlman's description of MIMO systems, were well-known by the Critical Date, and thus, their combination would have predictably improved communication channel adaptability and throughput. APPLE-1004, 0006, 0008, APPLE-1008, 0019-0020, 0134-0136. Further, the combination would have involved use of known aspects of the control information for base station and UE communication coordination.

90. These motivations and discussions are applicable to the following

analysis. Kim, Dahlman and Kim-966 each represent analogous art to the '110 patent in dealing with improvements to 3GPP and LTE architectures.

91. The following annotated figure from Kim demonstrates the "journey" of the claimed ***first signal*** (CSI-RS) through the Combination. A first signal (CSI-RS) is transmitted from Kim's base station on a port group and received on its MIMO UE. Kim's CSI-RS are transmitted throughout a series of subframes within a first time resource pool. Kim-966 explains that the CSI-RS has an antenna virtualization vector that specifies the MIMO configuration on the UE. Kim explains that the antenna virtualization vector is available to the UE in the time resource pool. With this configuration, the UE can thus interface with a MIMO wireless network.



APPLE-1008, FIG. 12.

IX. MANNER IN WHICH THE PRIOR ART REFERENCES RENDER THE '110 CLAIMS UNPATENTABLE

A. Analysis - [GROUND 1] – [Kim, Dahlman, Kim-966]

1. Claim 1

[1.1] A method for multi-antenna transmission in a user equipment, comprising:

92. The Combination renders obvious [1.1]. Among other things, the Combination involves an architecture based on of 3G/LTE technology that allows communication between base stations and mobile devices (User Equipment (UE)).

APPLE-1004, 0002-0017; APPLE-1008, 0002, FIG. 1-4, 22. Indeed, Kim discloses structure "employ[ing] ***multiple antennas*** based on a Multiple Input Multiple Output (MIMO) scheme, and us[ing] various technologies, such as beam-forming, Adaptive Modulation and Coding (AMC), channel sensitive scheduling, and the like." APPLE-1004, 0006. Specifically, Kim describes "generating channel state information [for] Multiple Input Multiple Output (MIMO) [***multi-antenna***] ***transmission*** and reception." APPLE-1004, 0016, 0017("Another aspect of the present invention is to provide an effective transmission and reception ***method*** in a MIMO system having scores or more transmission antennas."), 0047("an exemplary method of effective transmission and reception of a reference signal in a massive Multiple Input Multiple Output (MIMO) wireless communication system which transmits data by using scores or more transmission antennas will be described.").

93. Kim's architecture describes that the base station and UE have multiple transmit and receive antennas. APPLE-1004, FIG. 3, 0051(" . . . the number of spatial channels which one UE can receive is determined depending on the number of reception antennas owned by the UE and the channel condition."). Further, a POSITA would have understood and found obvious that in a MIMO architecture both base stations and UEs would have multiple antennas for transmission and reception. APPLE-1007, Section 5.5, FIG. 5.14. In fact, Dahlman

explains that "[t]he term MIMO (Multiple-Input/Multiple-Output) antenna processing is also very often used, although the term strictly speaking refers to all cases of multiple transmit antennas and multiple receive antennas, including the case of combined transmit and receive diversity." APPLE-1007, p.89.

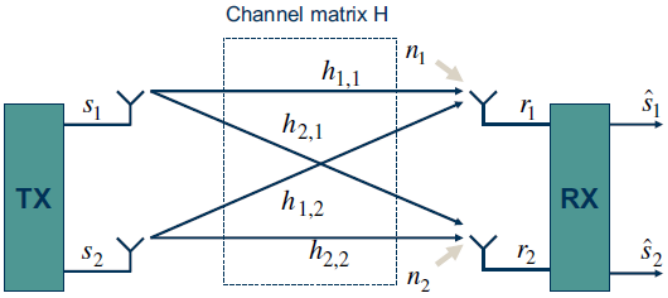


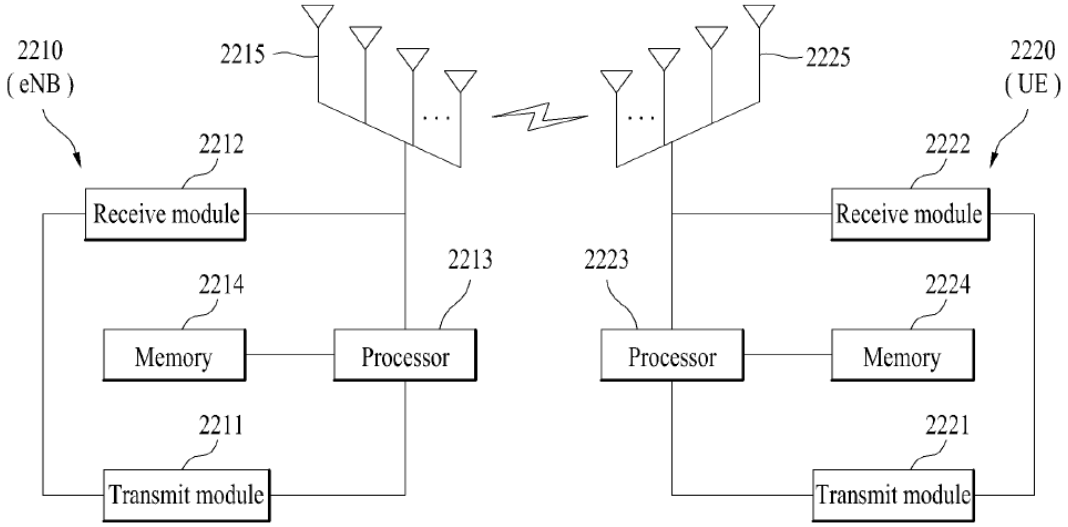
FIGURE 5.14

2 × 2 antenna configuration

APPLE-1007, FIG. 5.14.

94. Similarly, Kim-966 shows the well-known nature of MIMO architecture. For example, Kim-966 describes that the transmission capacity of MIMO increases with the number of transmit and receive antennas associated with each device—a discovery as far back as the 1990s. APPLE-1008, 0209-0214, FIG. 22.

FIG. 22



APPLE-1008, FIG. 22.

95. Thus, the Combination renders obvious a ***user equipment*** deploying ***multi-antenna transmission***. APPLE-1004, 0016, 0017; APPLE-1008, 0209-0214, FIG. 22.

[1.2] receiving a first radio signal; and

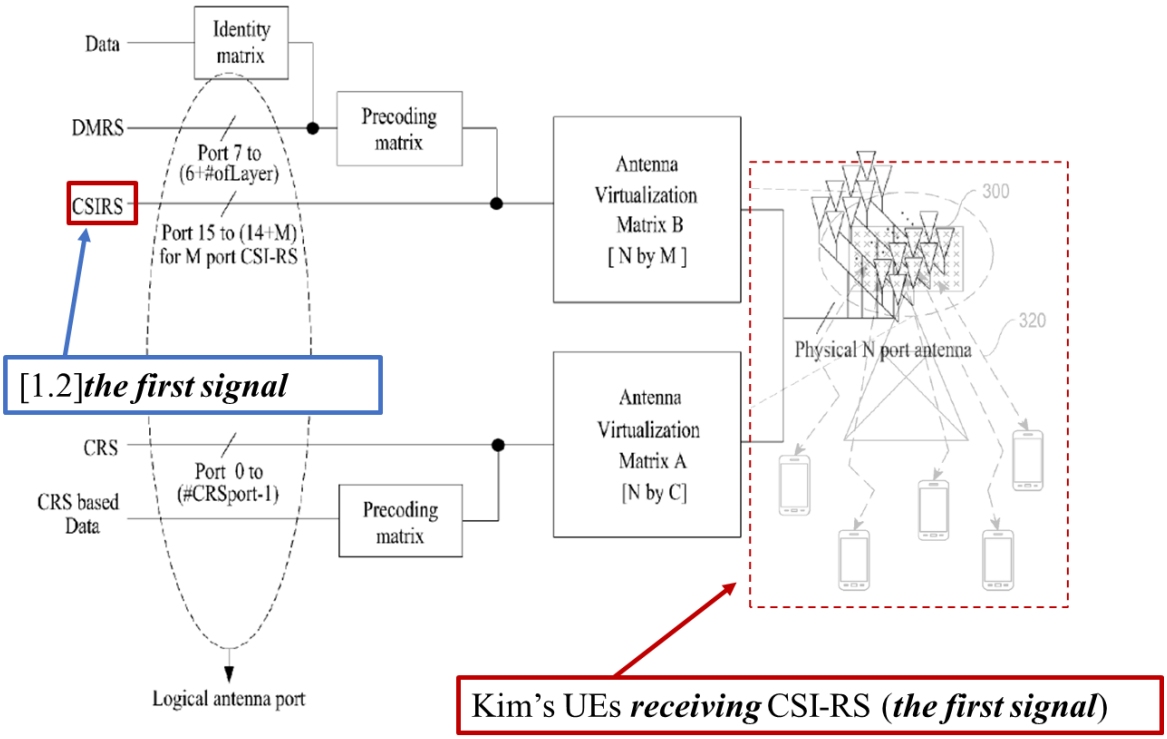
96. The Combination renders obvious [1.2]. For example, Kim describes "a UE apparatus for ***receiving*** a reference signal for generation of channel state information [(CSI)] in a wireless communication system." APPLE-1004, 0019. The Kim reference signal is a first radio signal, and its UE receives the reference signal from a base station that transmits "a CSI-RS [(channel state information reference signal)] for a massive MIMO system." APPLE-1004, 0055, 0021.

97. In greater detail, Kim's UEs receive the channel state information reference signal (CSI-RS) (***a first radio signal***) for the purpose of channel optimization. APPLE-1004, 0092-0097. Kim confirms that "[t]he first CSI-RS is a signal [(***a first radio signal***)] which is periodically transmitted and received by a plurality of UEs" for the purposes of each UE measuring the channel conditions. APPLE-1004, 0095. This is consistent with later element [1.10] that recites "***the first radio signal*** includes one or more of . . . [a] CSI-RS [Channel State Information Reference signal]."

98. Thus, a POSITA would have found obvious from the Combination that a UE receives a CSI-RS, and thus, a UE ***receiving a first radio signal***.

99. Kim-966's figure 12 provides a helpful visual aid in demonstrating some of the various claim elements, particularly those elements related to "the first signal." In figure 12, Kim-966 shows a representation of the connection from CSI-RS antenna ports generating a CSI-RS to the ultimate transmission of those CSI-RS. Kim's base station antenna array from figure 3 is overlayed onto Kim-966's base station antenna array to represent the reception of CSI-RS at the UE (as claimed). The petition will provide the following annotated figure 12 of Kim-966 to demonstrate the claimed elements dealing with the ***first radio signal*** (claim elements 1.2, 1.4, 1.5, 1.7-1.10).

FIG.12



APPLE-1008, FIG. 12 modified with APPLE-1004, FIG. 3.

[1.3] receiving a first signaling;

100. The Combination renders obvious [1.3]. Kim, for example, discloses a UE "***receiving*** control information [(***a first signaling***)] ... for controlling the first reference signal receiver." APPLE-1004, 0021, 0065. Kim further states that this "an eNB should notify a UE of related control information before transmitting a CSI-RS" and that this "control information is imperative for proper reception of the CSI-RSs." APPLE-1004, 0065. Dahlman mirrors the necessity of control information for proper reception, and provides detailed examples of such control information. APPLE-1007, pp.355-362. For example, Dahlman describes

information "which needs to be acquired by terminals [UEs] in order for them to be able to access and, in general, operate properly within the network." APPLE-1007, pp.355-362. Specifically, Dahlman describes a "system information block" ("SIB") which can include various types of information such as "information about the allocation of subframes to uplink/downlink and configuration of the special subframe in the case of TDD." APPLE-1007, pp.358-362; APPLE-1004, 0065, 0065-0072. A POSITA would have understood that the information conveyed in an SIB as described in Dahlman (such as the uplink/downlink configuration of subframes), is a type of "control information" that Kim describes. Such knowledge is corroborated, for example, by Park (APPLE-1011), which explains that "uplink-downlink configurations may be known to both an eNB and UE as system information" and are indicated by "the index of uplink-downlink configuration information" where that "configuration information is kind of **downlink control information**." APPLE-1011, 0063;.

101. Based on the disclosure from Kim and Dahlman, a POSITA would have understood and found have found obvious to implement Kim's control information, which is received by the UE, as a System Information Block (SIB) (***a first signaling***), as taught by Dahlman, because the SIB is a type of control information sent from the base station to the UE (e.g., through a downlink shared channel (DL-SCH)) as described in Dahlman. APPLE-1007, pp.358-362 ("System-

Information Blocks (SIBs) that are transmitted using the DL-SCH."). Thus, a POSITA would have understood and found obvious that ***a first signaling*** (SIB) is ***receive[ed]*** by the UE through the DL-SCH. APPLE-1007, pp.358-362.

102. This is consistent with the '110 disclosure. For example, later elements of the '110 patent claims and specification describe ***a first signaling*** in a manner consistent with Dahlman's description of SIB. APPLE-1001, 4:1-4 ("the first signaling is carried by a downlink physical layer control channel (i.e. a downlink channel that can only be used to carry physical layer signaling)"). Element [1.11] recites "the first signaling is a downlink signaling" and a SIB is part of the Downlink Shared Channel. APPLE-1007, pp.358-362. Elements [1.6] recite "the first signaling is used to determine a first time resource pool" and [2.4] a "signaling is used to determine the first time resource sub-pool from the first time resource pool"—the SIB is used for scheduling including "the allocation of subframes to uplink/downlink and configuration of the special subframe in the case of TDD." APPLE-1007, pp.358-362. Claim [5] recites "the first signaling is for the UE" and a SIB is "information that terminals [UEs] need in order to be able to access the cell." APPLE-1007, pp.358-362.

[1.4] wherein the first radio signal is transmitted by K antenna port groups; the[2] antenna port group includes a positive integer number of antenna port(s);

103. The Combination renders obvious [1.4]. Kim, for example, discloses a CSI-RS (***the first radio signal***) being ***transmitted*** to a UE ***by K antenna port groups*** of the base station. APPLE-1004, 0012, 0022, FIG. 2.

104. Kim teaches that, when transmitting CSI-RS, the "LTE-A system can support signals for one antenna port, 2 antenna ports, 4 antenna ports, and 8 antenna ports." APPLE-1004, 0010. Kim's disclosure demonstrates that the UE receives ***the first radio signal*** that ***is transmitted by*** multiple (i.e., ***K***) ***antenna port groups*** of the base station. The concept of CSI-RS transmission through multiple CSI-RS ports is discussed in more detail below.

105. In MIMO systems it was common to use multiple antenna ports divided into groups for the transmission of signals—especially for CSI-RS transmissions. APPLE-1004, 0010; APPLE-1008, 0073-0078. Kim illustrates this in FIG. 2, where an example transmission of a CSI-RS uses four assigned CSI-RS antenna ports divided into two antenna port groups.

[2] There is no antecedent basis for this term.

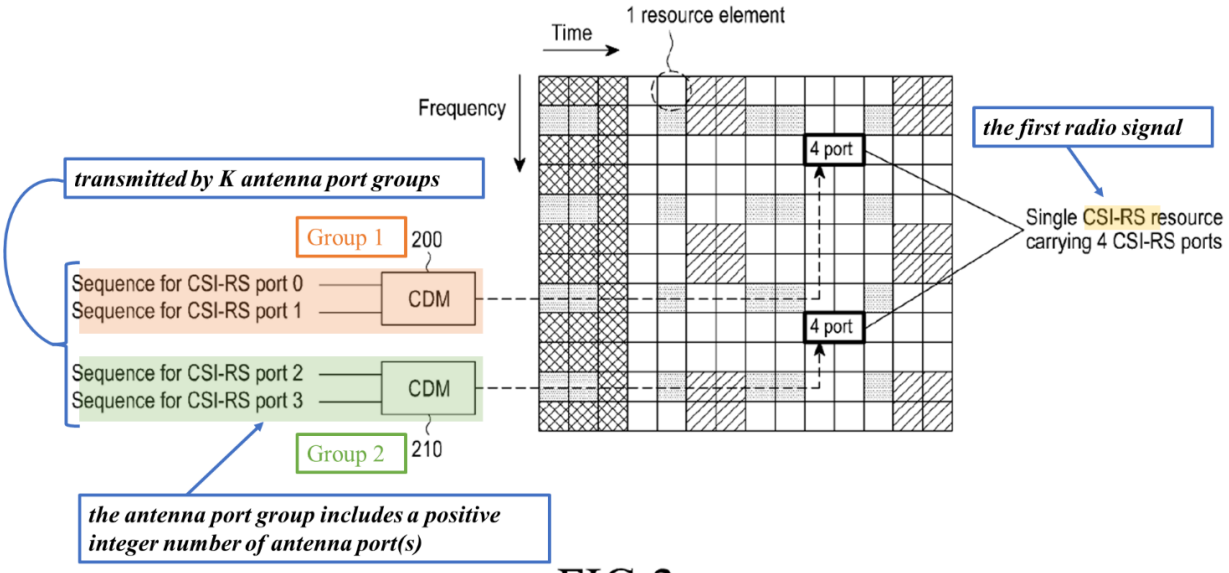


FIG.2
(RELATED ART)

APPLE-1004, FIG. 2.

106. More specifically, Kim's FIG. 2 demonstrates the use of ***K antenna port groups*** (e.g., two antenna port groups in FIG. 2), where each antenna port group contains two antenna ports (***the antenna port group includes a positive integer number of antenna port(s)***). APPLE-1004, 0011-0012. In FIG. 2 and the accompanying description, a first antenna port group contains CSI-RS ports 0 and 1 while a second antenna port group contains CSI-RS ports 2 and 3. And, in its Fig. 2 example, Kim transmits the CSI-RS signal (***the first radio signal***) using two groups together (***K^3 antenna port groups***). APPLE-1004, 0011-0012.

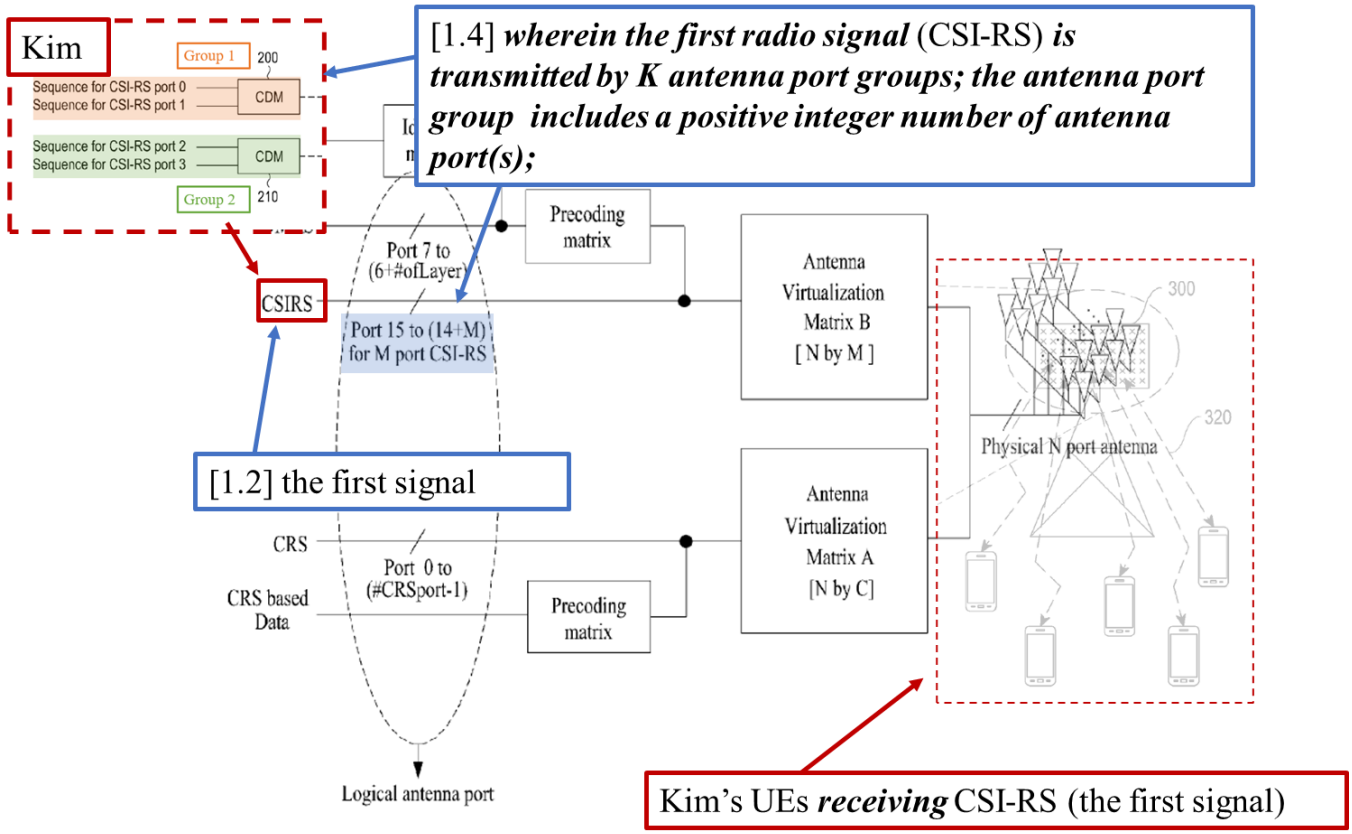
[3] Claim element [1.9] limits K to two or more.

107. Kim-966 also describes the well-known use of multiple CSI-RS antenna ports in pairs (***antenna port groups***) for transmission. APPLE-1008, 0074-0078. Specifically, Kim-966 describes the use of eight CSI-RS antenna ports (ports 15-22) in groups of two, where the antenna ports within a group are orthogonalized through the CDM process. APPLE-1008, 0074-0078, 0083; APPLE-1007, p.186("The antenna ports corresponding to CSI-RS are referred to as antenna port 15 up to antenna port 22 in the LTE specification.").

108. As noted, each of Kim and Kim-966 offers an example of antenna port pairs (***antenna port groups***) used for CSI-RS. Each of these antenna port groups (CSI-RS antenna port groups) use Code Division Multiplexing (CDM), and thus, Kim and Kim-966 provide independent examples of ***the first radio signal*** (CSI-RS) being ***transmitted by K antenna port groups***. APPLE-1004, 0009-0014; APPLE-1008, 0077. Additionally, the use of CDM involves pairs of antenna ports arranged in antenna port groups, thus each ***antenna port group includes a positive integer number of antenna port(s)*** (e.g., two antenna ports paired through CDM). APPLE-1004, 0011-0012; APPLE-1007, Section 10.2.3.1, pp.186-188; APPLE-1008, 0104; APPLE-1009, pg. 8 ll. 29-35("In some embodiments, the CSI-RS may be divided into several groups, and each CSI-RS group may include K antenna ports. In one example, K may be equal to 2").

109. Thus, a POSITA would have understood and found obvious from the

Combination that when transmitting CSI-RS in a MIMO LTE system, that antenna ports are commonly assigned to transmit CSI-RS across multiple groups where each group includes a pair of antenna ports. And based on the Combination, a POSITA would have further understood and found obvious that ***the first radio signal*** (a CSI-RS) ***is transmitted by K antenna port groups*** (e.g., the pairs of antenna ports utilizing CDM)***; the antenna port group includes a positive integer number of antenna port(s)***.

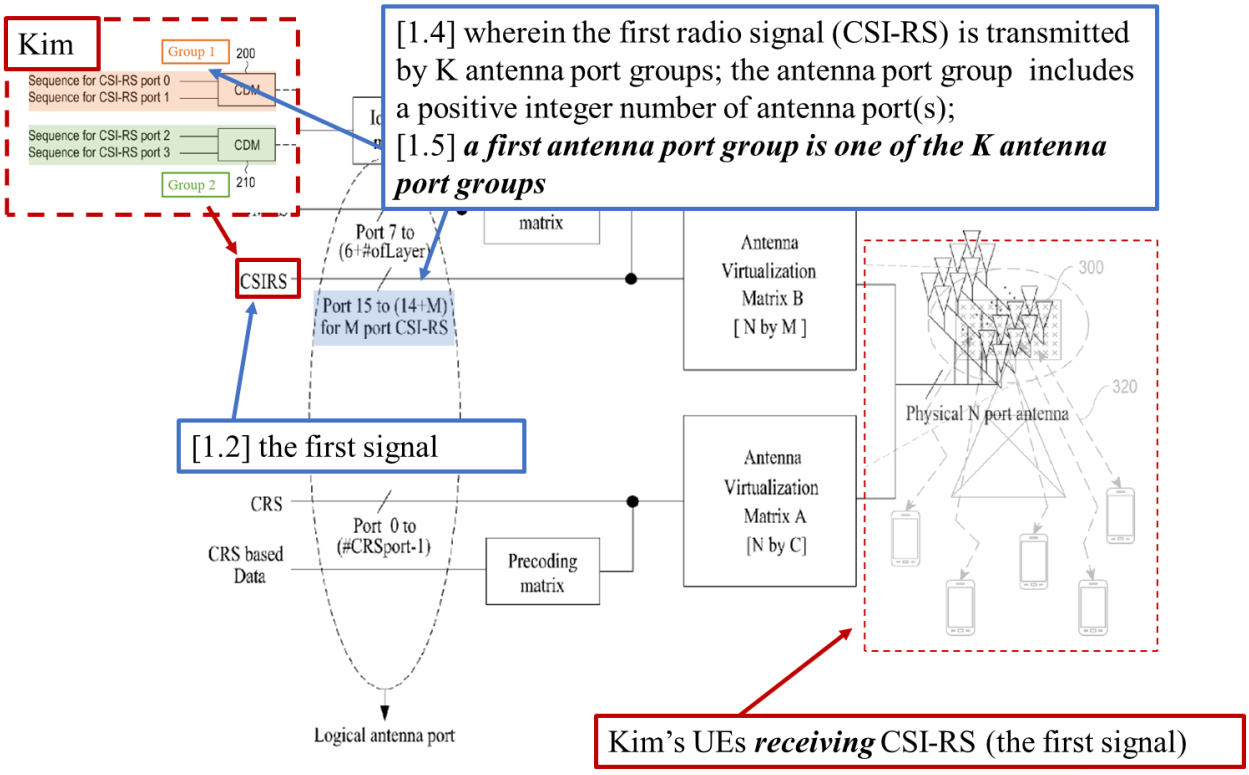


APPLE-1008, FIG. 12 modified with APPLE-1004, FIG. 2 and 3.

[1.5] a first antenna port group is one of the K antenna port groups;

110. The Combination renders obvious [1.5]. As discussed in [1.4], Kim discloses multiple antenna port groups, for example in figure 2. APPLE-1004, 0011-0012, FIG. 2. Kim-966 similarly discloses CSI-RS antenna port CDM groups. A POSITA would have understood and found obvious that one of the multiple port groups is ***a first antenna port group*** which ***is one of the K antenna port groups*** especially given the disclosure of the two antenna ports in Kim's figure 2 and the antenna port groups of Kim-966. APPLE-1004, 0011-0012, FIG. 2; APPLE-1008, 0084-0087.

111. In other words, of all the allowable CSI-RS antenna ports (***the K antenna ports***) (e.g., up to a total of eight with defined port numbers 15-22), ***a first antenna port group is one of the K antenna port groups***. APPLE-1004, FIG. 3; APPLE-1007, FIG. 10.13; APPLE-1008, 0084-0087.



APPLE-1008, FIG. 12 modified with APPLE-1004, FIG. 2 and 3.

[1.6] the first signaling is used to determine a first time resource pool;

112. The Combination renders obvious [1.6]. As discussed in [1.3], it would have been obvious to implement Kim's "control information" using Dahlman's SIB (***the first signaling***), described also in Kim-966. *See* [1.3]; APPLE-1004, 0065-0072, 0079, 0091; APPLE-1008, 0056. Indeed, Dahlman indicates that SIB "includes information about the allocation of subframes to uplink/downlink and configuration of the special subframe in the case of TDD." APPLE-1007, pp.358-362; APPLE-1004, 0065, 0065-0072.

113. Because the SIB assigns time resources or an "allocation of subframes

for uplink/downlink," an SIB would be understood to function as and render obvious as assigning the UE a collection of time intervals (e.g., subframes) or "***time resource pools***." APPLE-1007, pp.358-362; APPLE-1004, 0060-0061, 0064-0078, 0084. Thus, a POSITA would have understood and found obvious that ***the first signaling*** (SIB) ***is used to determine*** an "allocation of subframes to uplink/downlink" (***a first time resource pool***) through an assignment of a Time Division Duplexing (TDD) configuration. The TDD configuration would identify a series of subframes available for uplink and downlink (a ***first time resource pool***). Shown in Dahlman's annotated figure 9.7 below, a particular configuration for TDD would establish a "pool" (Dahlman's "allocation of subframes") of the downlink and uplink subframes (***time resources***) assigned to a UE. APPLE-1004, 0061, 0069; APPLE-1007, pp.358-362, FIG. 9.7.

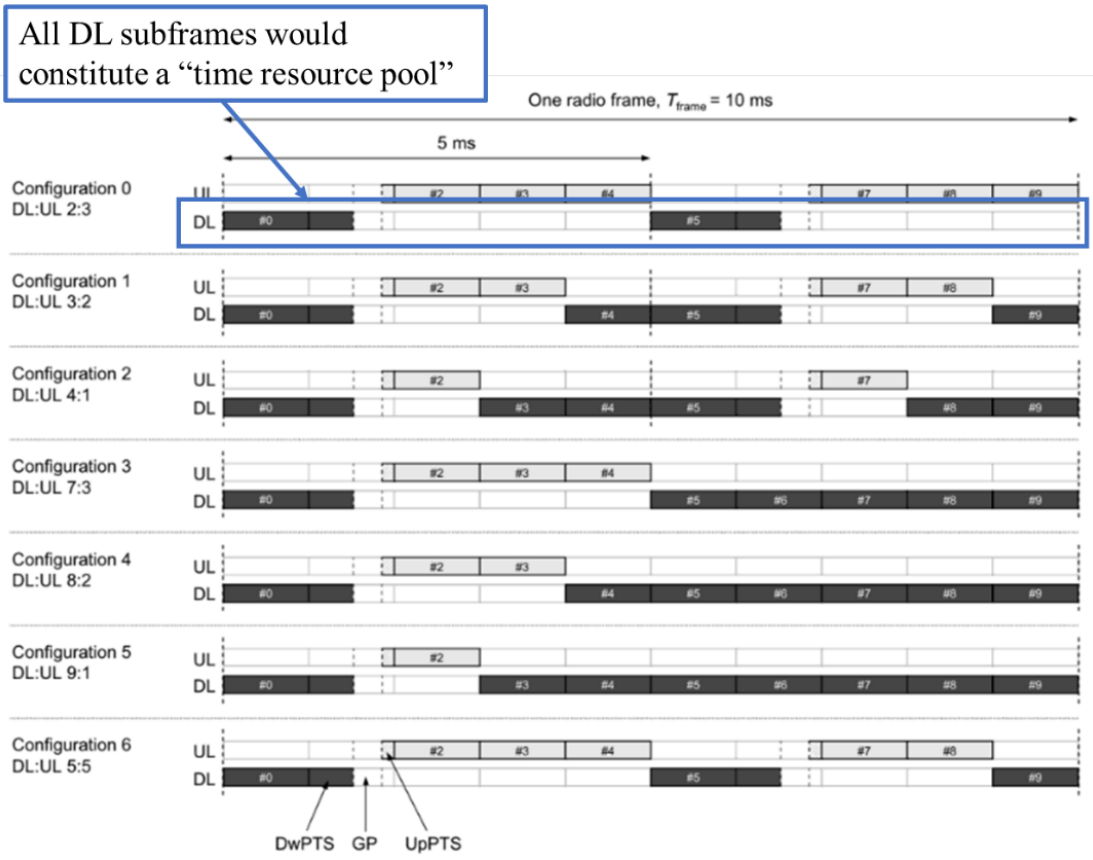


FIGURE 9.7

Different downlink/uplink configurations in case of TDD

APPLE-1007, FIG. 9.7.

114. Given the well-known nature of TDD configurations of the type shown in Fig. 9.7 of APPLE-1007, a POSITA would have understood and found obvious ***the first signaling*** (SIB), which "includes information about the allocation of subframes to uplink/downlink and configuration" using TDD configurations. Further, a POSITA would have understood and found obvious that these uplink or downlink subframes represent time resources and thus the SIB ***is used to determine a first time resource pool***.

115. This mapping is consistent with the '110 Patent disclosure relating ***a first time resource pool*** with a collection of subframes. The '110 Patent describes the assignment of time resources is accomplished through a "time resource pool" which is formed of "subframes," where a set of these can make a "sub-pool." APPLE-1001, 16:5-14("the subframe #3 and #7 in the first time resource pool {#1, #3, #5, #7} consists of the first time sub-pool"); FIG. 4-9. Based on the plain language of the claim and in light of the specification,. A POSITA would have understood that "time resources" refers to periods or slots of time, such as a collection or pool of subframes. *See also* APPLE-1006, p.116(applicant stating, during prosecution, that "one having ordinary skill in the art of wireless and cellular communication understands that different time slots (also referred to commonly as 'time resources') are grouped together into 'pools' and selected for certain transmissions.").

116. Thus, a POSITA would have understood and found obvious that the SIB is ***the first signaling*** which ***is used to determine a first time resource pool*** consisting of the downlink or uplink subframes assigned to the UE through TDD configurations.

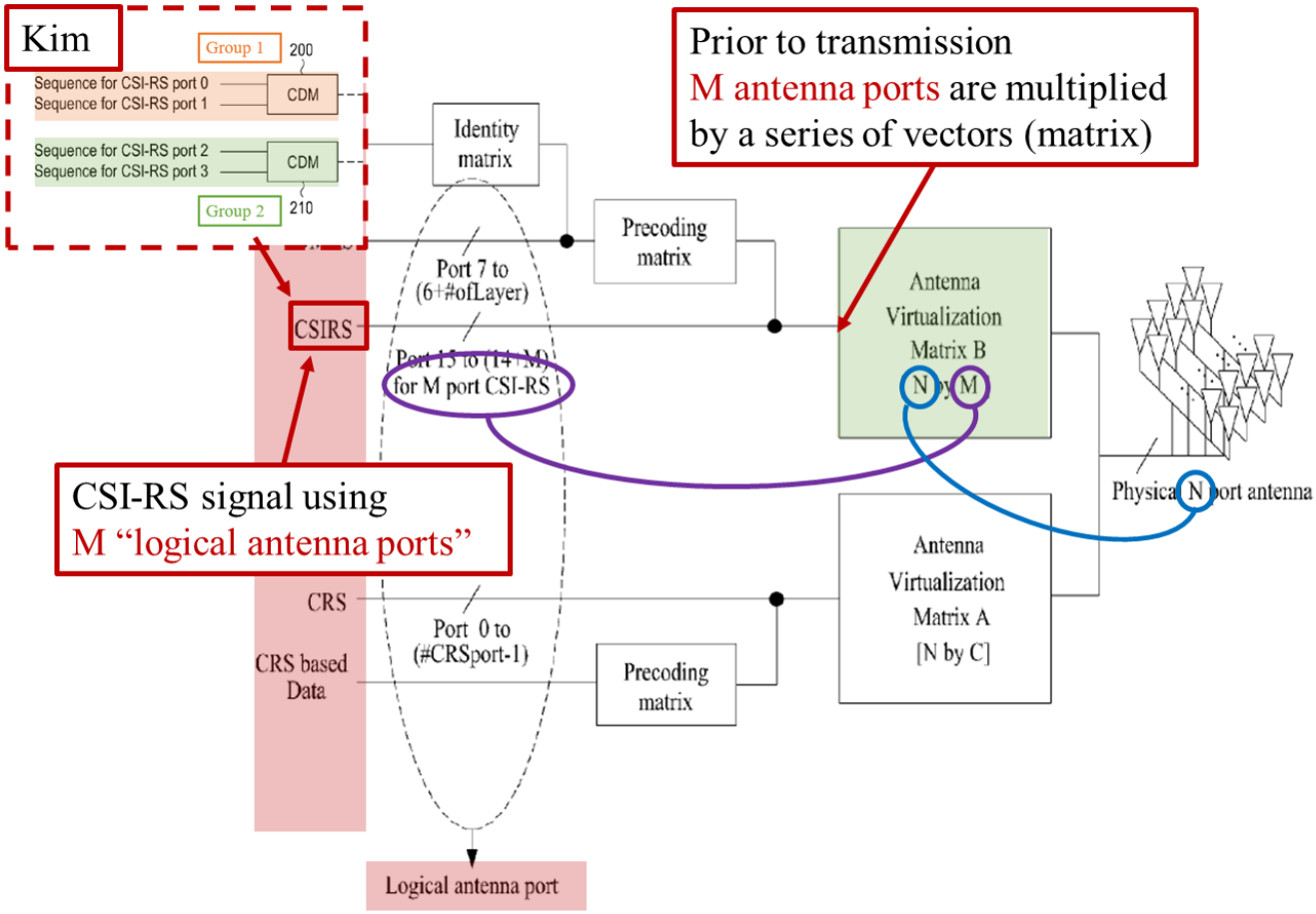
[1.7] a second[4] antenna virtualization vector is associated with the first antenna port group;

[4] The claims do not define a "first" antenna virtualization vector.

117. The Combination renders obvious [1.7]. By way of background, Kim discusses the need for mapping of antenna port signals to transmission antenna. APPLE-1004, 0017("transmission and reception method in a MIMO system having scores or more transmission antennas."), 0051("A proper precoding [mapping] scheme is applied to a plurality of transmission antennas, so as to enable simultaneous transmission to the plurality of transmission antennas."). Such a mapping provides for transmission using "the plurality of transmission antenna" because each of the antenna ports, prior to transmission, coordinates (through an antenna virtualization vector) with a physical antenna for transmission. APPLE-1004, 0051.

118. Kim-966 provides further details of how to implement antenna virtualization for mapping antenna ports (e.g., CSI-RS antenna ports) to physical antenna elements APPLE-1008, 0016, 0086-0087, Table 3, 0136; APPLE-1007, 273("antenna virtualization is used. . . to map the two-antenna-port signal to four physical antennas."). In particular, Kim-966 provides antenna virtualization vectors as a solution to this need to coordinate antenna ports with physical antennas. APPLE-1008, FIG. 12, 0136, 0141. Antenna virtualization vectors enabled antenna ports to be agnostic to the number of antennas physically present in a base station or UE. Put differently, antenna virtualization vectors were used to scale the virtual antenna ports to the physical antenna ports for transmission or

reception. One such example appears in Fig. 12 of Kim-966, which demonstrates how several signals transmitted from a system leverage an antenna virtualization matrix (collection of antenna virtualization vectors) for mapping an antenna port to the physical antennas precisely before transmission. APPLE-1008, FIG. 12, 0136, 0141.



APPLE-1008, FIG. 12 and APPLE-1004, FIG. 2.

119. Kim's physical antenna array would leverage Kim-966's representation of a variable number of ports and antennas. APPLE-1004, 0051;

APPLE-1008, FIG. 12, 0136. In this combination, Kim-966's demonstration of an ***antenna virtualization vector*** leverages the association of antenna ports to physical antenna. APPLE-1004, 0052; APPLE-1008, FIG. 12, 0136.

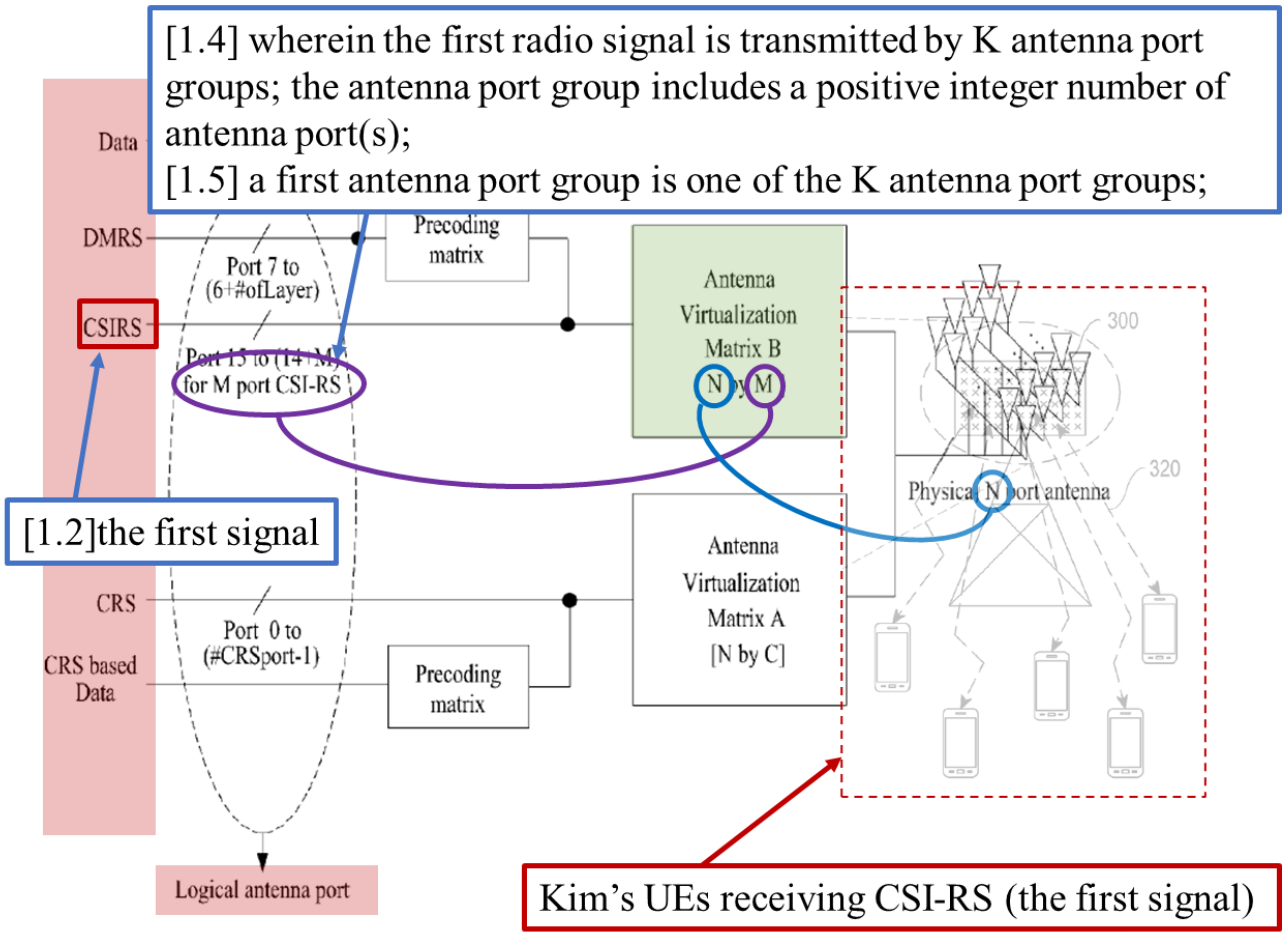
120. In greater detail, Kim-966's antenna virtualization matrix would include one or more an antenna virtualization vectors that would be ***associated with*** an ***(the first) antenna port group*** (e.g., CSI-RS antenna port group pairs). APPLE-1007, 196(a "matrix W is a vector of size $N_A \times 1$"); APPLE-1004, FIG. 2, 0011-0013. Kim-966 demonstrates in detail the grouping of standard's designated CSI-RS antenna ports (15-22) into CDM groups, where each group includes two antennas (each pair being an ***antenna port group***). *See* [1.4]; APPLE-1008, 0074-0079, 0083; APPLE-1004, 0011-0013, FIG. 2: APPLE-1007, 189-190. Thus, each of these pairs, when subject to a CDM process, provide an output signal representing the CSI-RS ***antenna port group***. *Id*. The output from the process, that is, the CSI-RS antenna port group, is then multiplied by an antenna virtualization vector (part of the antenna virtualization matrix of Kim-966's figure 12).

121. As another example, Kim-966 discloses that "a signal after antenna virtualization may be represented as $Z=[z_1, z_2, \ldots, z_N]=B*X$" where "$z_i$ denotes a precoding vector for the i-th CSI-RS antenna port" (the "precoding vector" being another example of ***a second antenna virtualization vector***). APPLE-1008, 0136.

122. The Combination of Dahlman and Kim-966 demonstrate that antenna

virtualization, used to map the standard defined virtual antenna ports to the number of available physical antenna of a device, was a well-known concept prior to the Critical Date. Because the association of antenna ports to physical antenna through virtualization was a fundamental concept in MIMO (demonstrated in disclosure above), a POSITA would have found obvious from the Combination that ***a second antenna virtualization vector*** (used for transmission of the first signal in [1.2] and [1.5]) ***is associated with the first antenna port group***. The above mapping is consistent with the'110 Patent which states that "the mapping coefficients from the multiple physical antennas to the antenna port(s) constitute an antenna virtualization vector for the antenna virtualization." APPLE-1001, 2:37-41.

123. Below a brief recap of the elements with an accompanying figure to put into context the individual elements of the claim.



APPLE-1008 modified with APPLE-1004, FIG. 3.

124. The above annotated figure demonstrates the "journey" of the claimed ***first signal*** (CSI-RS). The first signal (CSI-RS) is transmitted using the known CSI-RS antenna port pairs (***antenna port groups***). At least one of those antenna port groups is associated with a single antenna virtualization vector (for example, a vector within Kim-966's "antenna virtualization matrix" or, as another example, Kim's "precoding vector" that results from applying virtualization, as discussed above). The base station uses or "associates" the CSI-RS ***antenna port group*** with

an ***antenna virtualization vector*** for transmission. This allows a system to be agnostic to the number of antennas the system may have. Thus, the claimed UE "receives" ***the first signal*** [1.2]...***transmitted by K antenna port groups*** [1.4]....at least one of those groups (***a first antenna port group***) associated with ***an antenna virtualization vector*** [1.5 and 1.7].

> ***[1.8] the second antenna virtualization vector is an antenna virtualization vector available to the user equipment in the first time resource pool; and***

125. The Combination renders obvious [1.8]. As discussed in [1.7], ***antenna virtualization vectors*** are used to map signals from antenna ports to physical antennas. *See* [1.7]. As discussed in [1.6], ***the first time resource pool*** defines a collection of subframes for UE reception. *See* [1.6]. ***The antenna virtualization vector*** being "***available***" for use by the ***UE in the first time resource pool*** allows for the UE to properly receive signals transmitted with multiple antenna port groups. APPLE-1004, 0065.

126. Specifically, Kim-966 describes using information transmitted to the UE about the CSI-RS configuration to determine the number of antenna ports being used. APPLE-1008, 0086-0087, Table 3. In this configuration information, the "antenna virtualization matrix B [] used for CSI-RS transmission. . . may be designated/configured for each UE." APPLE-1008, 0136, *see also* 0141 ("eNB establishes K CSI-RS transmission configurations and assigns an antenna

virtualization matrix B, to each configuration" and the "eNB may inform the UEs of only some CSI-RS transmission configurations efficient for the UEs among K CSI-RS transmission configurations"). Thus, in designating the antenna virtualization vector "for each UE" and informing/transmitting such configuration information to the UE, the ***antenna virtualization vector*** is ***available to the user equipment in the first time resource pool***. APPLE-1008, 0086-0087, Table 3, 0136. This "availability" allows the UE to use the antenna virtualization for proper reception of the signal. *Id*. Because reception at the UE occurs during a downlink subframe, the ***antenna virtualization vector*** is ***available to the user equipment in the first time resource pool***.

127. Hence, a POSITA would have understood and found obvious, in light of Kim-966's teaching of configuration information (including an antenna virtualization matrix including multiple vectors for each antenna port) that is informed to the UE for proper reception of CSI-RS, that ***the second antenna virtualization vector*** (used to transmit the first signaling (CSI-RS) to the UE) ***is an antenna virtualization vector available to the user equipment***. Indeed, this information enables proper reception at the UE. Finally, because the antenna virtualization vector would indicate the number of CSI-RS antenna ports used (e.g., 2, 4, or 8) and the number of antenna ports used would affect ***the second antenna virtualization vector*** which is ***available***, through Kim-966's configuration

information, ***to the UE in the first time resource pool***.

[1.9] the K is a positive integer greater than 1;

128. The Combination renders obvious [1.9], for example, through disclosure of multiple antenna port groups. For context, in [1.3] ***the first radio signal is transmitted by K*** [2 or more] ***antenna port groups***. APPLE-1004, 0009-0014, 0056-0060, FIG.4. Kim-966 furthers this understanding through an example of four antenna port groups, each group containing two antennas. APPLE-1008, 0074-0079, 0083 (CDM groups).

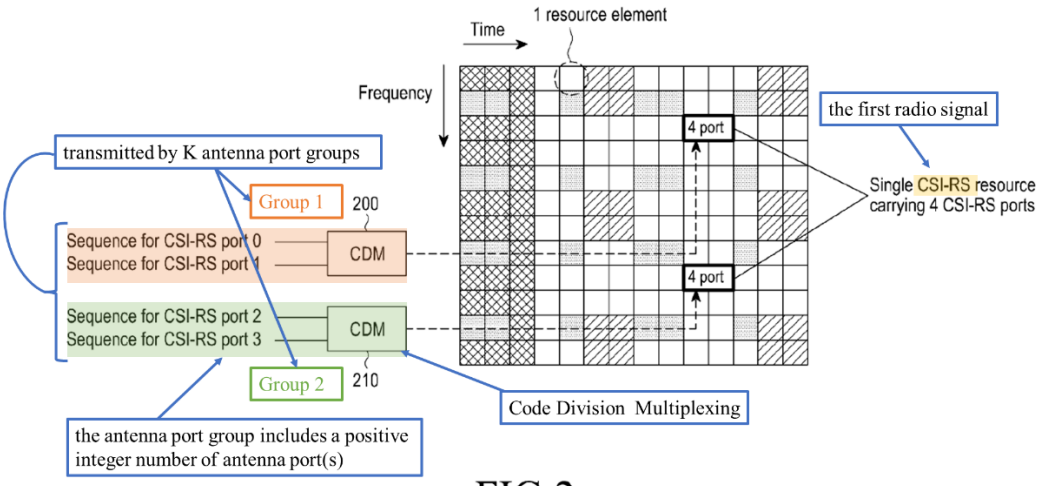


FIG.2
(RELATED ART)

APPLE-1004, FIG. 2.

129. Additionally, a POSITA would have understood and found obvious that in transmission of CSI-RS, the use of multiple antenna port groups was well-known in the art. For example, shown above in FIG. 2, Kim teaches antenna port

groups (K (2 or more) antenna port groups where ***K is a positive integer greater than 1***). Each of Kim and Kim-966's groups has two transmission antennas. APPLE-1004, 0010, FIG. 2; APPLE-1008, 0084-0087, 0136.

[1.10] the first radio signal includes one or more of PSS [Primary Synchronization Signal], SSS [Secondary Synchronization Signal], MIB [Master Information Block]/SIB [System Information Block] or CSI-RS [Channel State Information Reference signal];

130. The Combination renders obvious [1.10] through disclosure that ***the first radio signal includes one or more of . . . CSI-RS (Channel State Information Reference signal)***. *See* [1.2] (***receiving a first radio signal*** which is a CSI-RS).

[1.11] the first signaling is a downlink signaling.

131. The Combination renders obvious [1.11]. For example, the SIB (***the first signaling***) ***is a downlink signaling*** because it is carried by the Downlink Shared Channel (DL-SCH). APPLE-1007, pp.358-362; *See* [1.3].

2. Claim 2

[2.1] The method of claim 1, further comprising: receiving a second signaling; and

132. The Combination renders obvious [2.1]. For example, Kim discloses the UE receiving control information through PDCCH signals. APPLE-1004, 0065-0079, 0107. Kim teaches and a POSITA would have understood and found obvious that the PDCCH messages carrying the control information are transmitted periodically throughout the frames and subframes. *Id*.; APPLE-1004, 0010, 0107;

APPLE-1007, FIG. 13.7, Chapter 13. Thus, the UE ***receiv[es] a second signaling*** which is "information imperative for reception of the second CSI-RS may be transmitted through a Physical Downlink Control Channel (PDCCH)." APPLE-1007, 0107.

[2.2] operating a second radio signal in a first time resource sub-pool;

133. The Combination renders obvious [2.2]. For example, Kim discloses receiving a CSI-RS in a MIMO system in a period of OFDM symbols (***a first time resource sub-pool***). APPLE-1004, FIG. 2, 0009-0014. In light of Kim's disclosure and the knowledge demonstrated by Dahlman, a POSITA would have understood and found obvious that when receiving ***a second radio signal*** (a second CSI-RS), that this second CSI-RS would ***operat[e]*** (be transmitted or <u>received</u> as explained in [2.3]) in ***a first time resource sub-pool*** because the CSI-RS is transmitted within specific time resources (OFDM symbols) within a particular downlink subframe. APPLE-1004, FIG. 1-2, 11, 0009-0014, 0109-0114; APPLE-1007, Section 10.2.3.1, pp.186-189 (CSI-RS periodicity), FIG. 10.13. Thus, at least some of the time resources (OFDM symbols) of a subframe would have been understood and obvious to a POSITA as constituting ***a first time resource sub-pool***. Specifically, the *first time resource <u>pool</u>* is all downlink subframes and the ***first time resource <u>sub</u>-pool*** is a portion of those downlink frames assigned for CSI-RS as shown in figures 1 and 2 of Kim and Dahlman's FIG. 10.13. APPLE-1001, FIG. 4; APPLE-

1004, FIG. 2; APPLE-1007, Section 10.2.3.1, pp.186-189, FIG. 10.13.

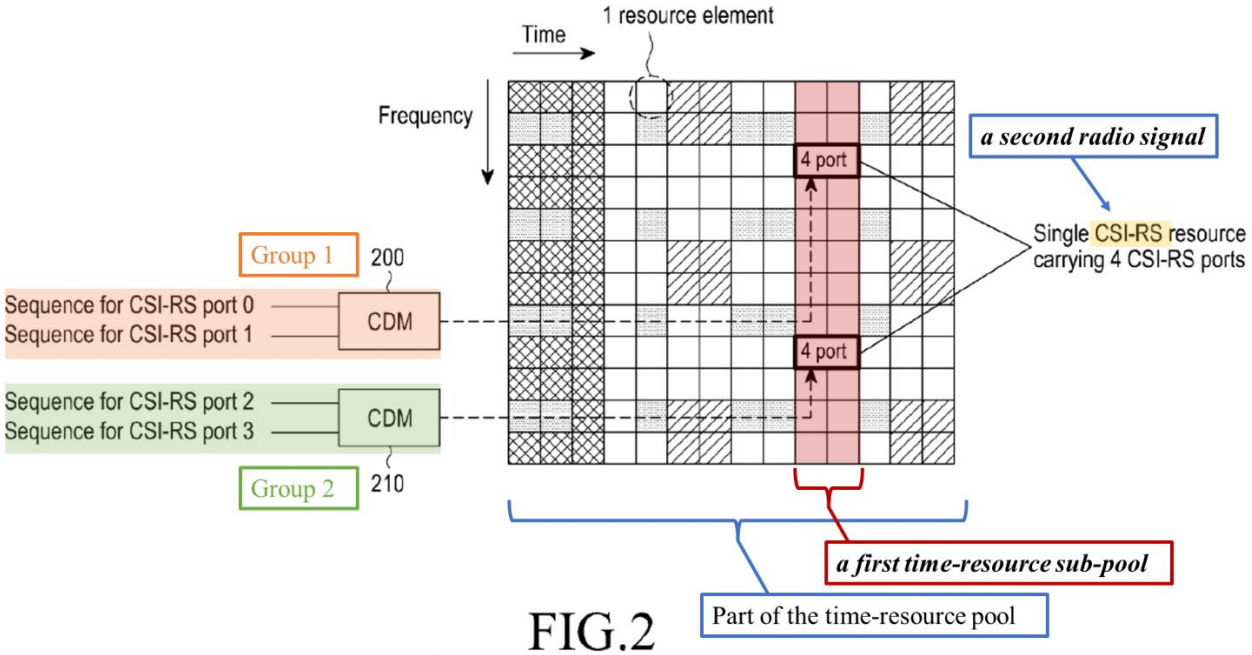


FIG.2
(RELATED ART)

APPLE-1004, FIG. 2.

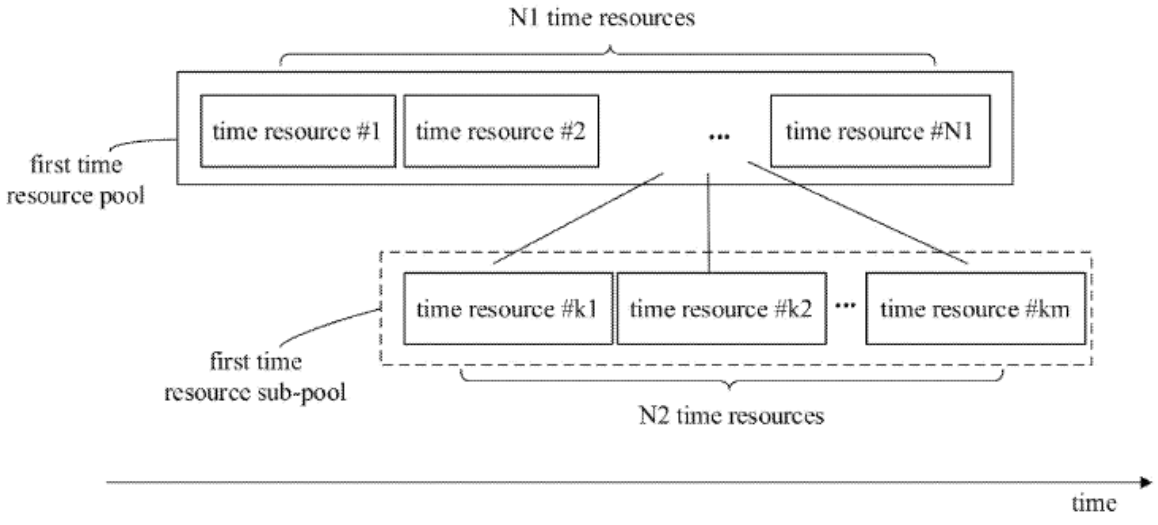


Fig. 4

APPLE-1001, FIG. 4.

134. As shown above, a POSITA would have understood and found obvious that the time resource pool, consisting of downlink subframes available to the UE, would have various numbers of time-resource sub-pools in which CSI-RS transmissions are received. APPLE-1001, FIG. 4; APPLE-1004, FIG. 2; APPLE-1007, Section 10.2.3.1, pp.186-189, FIG. 10.13. This mapping is consistent with the specification, for example in figure 4 and the accompanying description. APPLE-1001, 15:28-42; FIG. 4.

[2.3] wherein the operating is one of receiving or transmitting the second radio signal;

135. The Combination renders obvious [2.3]. Specifically, Kim demonstrates that ***operating is one of <u>receiving</u> . . . the second radio signal*** (CSI-RS). For example, Kim "illustrates a transmission of first CSI-RSs and second CSI-RSs for respective subframes" and the UE ***receiving*** from the base station these CSI-RS. APPLE-1004, 0036. Kim discloses that in a later point in time (a later subframe) a second CSI-RS is transmitted by the base station and received by the UE. The subsequent CSI-RSs serve to further refine the channel. APPLE-1004, 0110, FIG. 11-12. For example, in FIG. 11 below, a first and a second CSI-RS signal are transmitted at two points in time. The second CSI-RS is ***the second radio signal***.

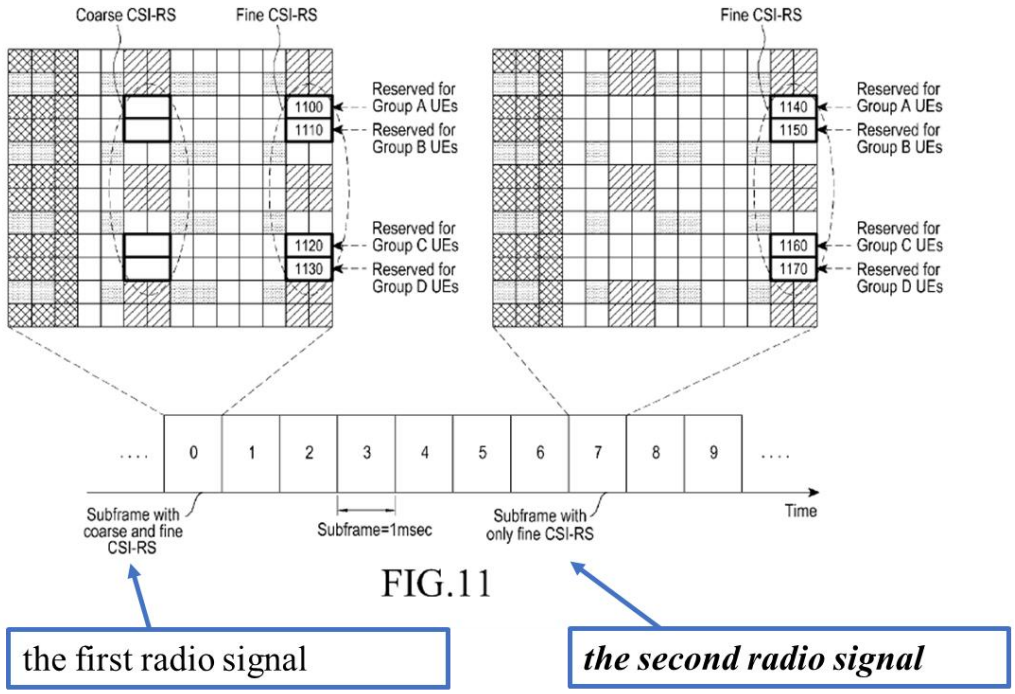


FIG.11

APPLE-1004, FIG.11.

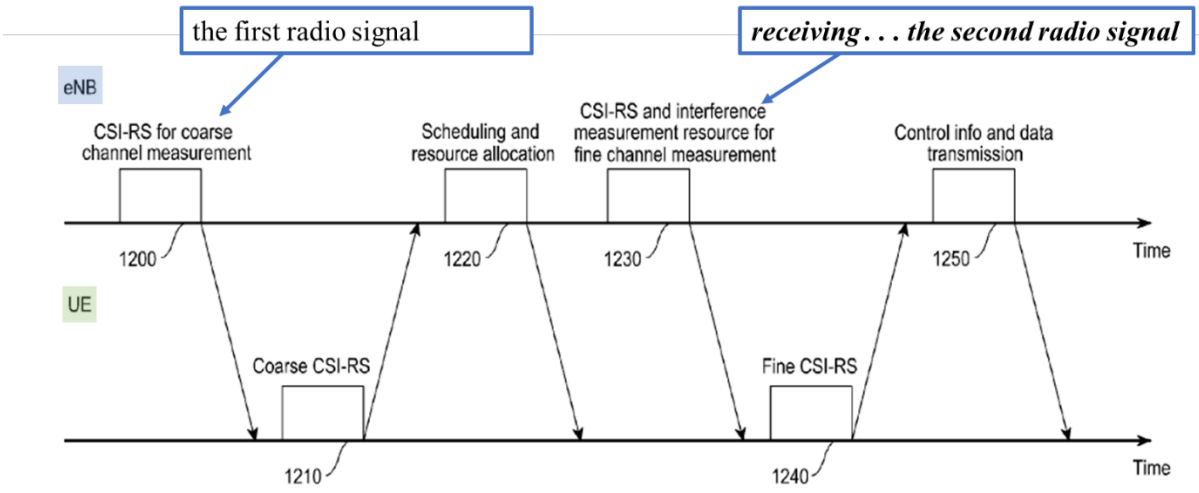


FIG.12

APPLE-1004, FIG.12.

[2.4] the second signaling is used to determine the first time resource sub-pool from the first time resource pool; and

136. The Combination renders obvious [2.4]. For example, Kim discloses the UE receiving scheduling and control information in a PDCCH (***the second signaling***). APPLE-1004, FIG. 1, 12, 0018-0021, *See* [1.6], [1.11]. Kim teaches the well-known concept that control information is repeatedly sent to UEs (e.g., in the control region). APPLE-1004, 0065, 0100(discussing a second transmission of "control information"), 0120, FIG. 9, 12. Indeed, a POSITA would have understood and found obvious that multiple PDCCHs, can exist in the control region of a subframe. APPLE-1007,

137. Kim discloses that the base station transmits to the UE "control information" that relates the "actual downlink wireless resources to be allocated" and is "needed for reception of a traffic channel to the selected UEs." APPLE-1004, 0018, 0065-0072, 0079, 0091. Moreover, "[i]n order to receive the second CSI-RSs, the eNB should transfer control information for receiving the second CSI-RSs to the UE." APPLE-1004, 0100. Kim's control information includes "information on a time interval" such as OFDM symbols in "which the second CSI-RS is transmitted." APPLE-1004, 0100-0108. An example of the ***time resource sub-pool*** with respect to a portion of the ***first time resource pool*** is annotated below in Kim's figure 2. As shown below and discussed in [1.6], Kim's figure 2 shows a single subframe which is a part of the larger ***first time resource***

pool.

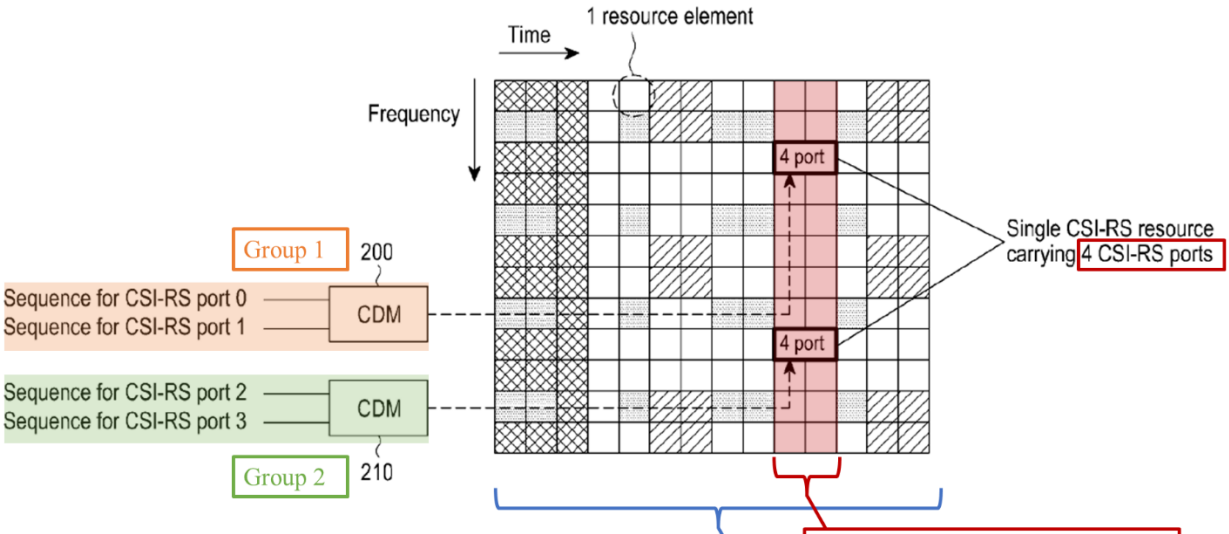


FIG.2
(RELATED ART)

APPLE-1004, FIG 2.

138. Therefore, the Kim's control information (***the second signaling***) that identifies "a time interval (i.e., a subframe) to which the second CSI-RS is transmitted;" determines ***the first time resource sub-pool from the first time resource pool***. In other words, ***the second signaling*** (Kim's "control information needed for reception") ***is used to determine the first time resource sub-pool*** (a period of OFDM symbols during which CSI-RS are received at the UE) ***from the first time resource pool*** (all downlink subframes assigned in TDD).

> ***[2.5] the second signaling is used to determine at least one of occupied frequency domain resources, an MCS [modulation and coding***

scheme], a HARQ process number, an RV [redundancy version], an NDI and (a) transmitting antenna port(s) of the second radio signal.

139. The Combination renders obvious [2.5]. For example, a POSITA would have understood and found obvious that Kim's control information (***the second signaling***) contains the elements recited in [2.5]. APPLE-1004, 0098-0108. Specifically, Kim discloses that the control information (***the second signaling***), includes "[i]nformation on a frequency band (i.e., an RB) to which the second CSI-RS is transmitted" or an ***occupied frequency domain resources***. APPLE-1004, 0102. Additionally, Kim discloses "[i]nformation on the number of transmission antenna ports through which the second CSI-RS is transmitted" or ***(a) transmitting antenna port(s) of the second radio signal***. APPLE-1004, 0105.

140. Thus, a POSITA would have understood and found obvious that the subsequently received control information (***the second signaling***) received at the UE is ***used to determine <u>at least one</u> of <u>occupied frequency domain resources</u>, an MCS [modulation and coding scheme], a HARQ process number, an RV [redundancy version], an NDI and <u>(a) transmitting antenna port(s) of the second radio signal</u>***.

3. <u>Claim 3</u>

[3.1] The method of claim 1, wherein the first signaling indicates the first antenna port group from the K antenna port group(s);

141. Element [3.1] is separated by an "or" and thus, satisfying element

[3.2] satisfies all of claim 3.

[3.2] or, comprising: receiving first information, wherein the first information is used to determine the first antenna port group.

142. The Combination renders obvious [3.2]. For example, Dahlman teaches that, among other things, the UE can receive system information in the form of a Master-Information Block (MIB) (***receiving first information***) which can indicate the antenna ports used. APPLE-1007, pp.355-362. Dahlman describes that the MIB is transmitted using the broadcast Channel (BCH). APPLE-1007, pp.355-357. By "detecting what transmit-diversity scheme is used for BCH, a terminal [UE] can indirectly determine the number of cell-specific antenna ports within the cell." APPLE-1007, pp.355-357. Thus, when a UE receives MIB in a BCH (***receiving first information***), ***the first information is used to determine the first antenna port group***. APPLE-1007, pp.355-357.

143. Dahlman further explains that the MIB (the "***first information***" in claim 3) and the SIB (the "*first signaling*" in claim 1) are collectively received by the UE as part of overall "system information." APPLE-1007, pp.355-357 (explaining that the MIB carries "a limited amount of system information" and the subsequent SIB carries the "main part of system information").

4. Claim 4

[4.1] The method of claim 1, further comprising: transmitting second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the

K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer;

144. The Combination renders obvious [4.1]. For example, Kim discloses the ***transmission*** from the UE to the base station of a CSI-RS report (***second information***) used to refine communications with the UE. APPLE-1004, 0080-0134. "[A] UE should precisely measure the channel state and the size of interference and transmit effective channel state information [(***second information***)] to an eNB by using the measured information." APPLE-1004, 0052.

145. Specifically, Kim's "channel state information" report (***second information***) is a standardized process elaborated on by Dahlman. APPLE-1004, 0119-0126. Dahlman describes the "channel state information" or "CSI report consists of Channel-Quality Indicator (CQI), Precoding Matrix Indicator (PMI), and Rank Indicator (RI)." APPLE-1007, p.292. Of these indications, the RI and PMI coordinate to report back the preferred channels (antenna ports) based on the received CSI-RS. APPLE-1007, 197, 292-293, 341-344. Thus, the second information (CSI Report) provides information used ***to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups***.

146. Kim teaches that this transmission of ***second information*** back to the base station is used to refine the communication channel. Indeed, Kim describes the refinement and selection of channels through multiple CSI-RS signals sent to the UE and multiple reports from the UE. APPLE-1004, 0090-0097, 0120-0126;

FIG. 9, 12.

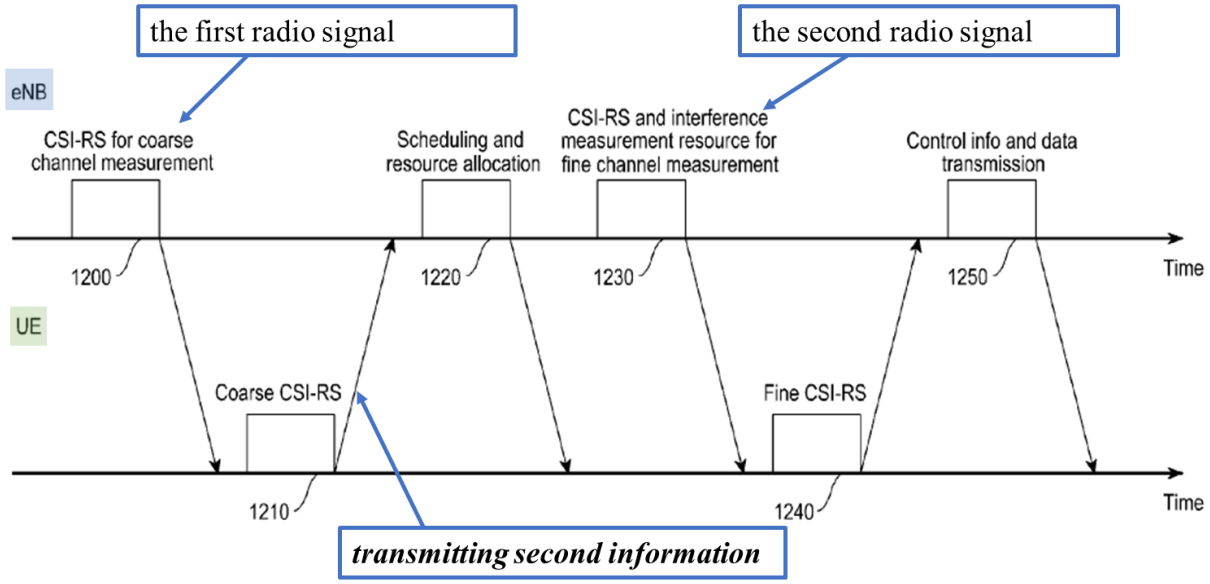


FIG.12

APPLE-1004, FIG. 12.

147. Thus, a POSITA would have understood and found obvious that when the UE transmits a report about the CSI-RS (***transmitting second information***) back to the base station, the CSI report includes antenna port information that is ***used to determine K1*** (where ***K1 is a positive integer) antenna port group(s).*** APPLE-1004, FIG. 2, 0009-0014, FIG. 12. This is because, for example, the RI indicates the channel quality based on antenna port groups. APPLE-1007, pp.197, 292-293, 341-344.

148. Therefore, ***the second information*** (CSI report) ***is used to determine K1 antenna port group(s)*** (the number of antenna port groups being used in CSI-

RS transmission, e.g., 2, 4, or 8)***; the K1 antenna port group(s) belong(s) to the K antenna port groups*** (the total number of CSI-RS ports allowed by the LTE standard, e.g., 8 antenna ports (4 antenna port groups))***; the first antenna port group*** (antenna ports 15 and 16 or Kim's CSI-RS ports 0 and 1) ***is one of the K1 antenna port group(s); the K1 is a positive integer.***

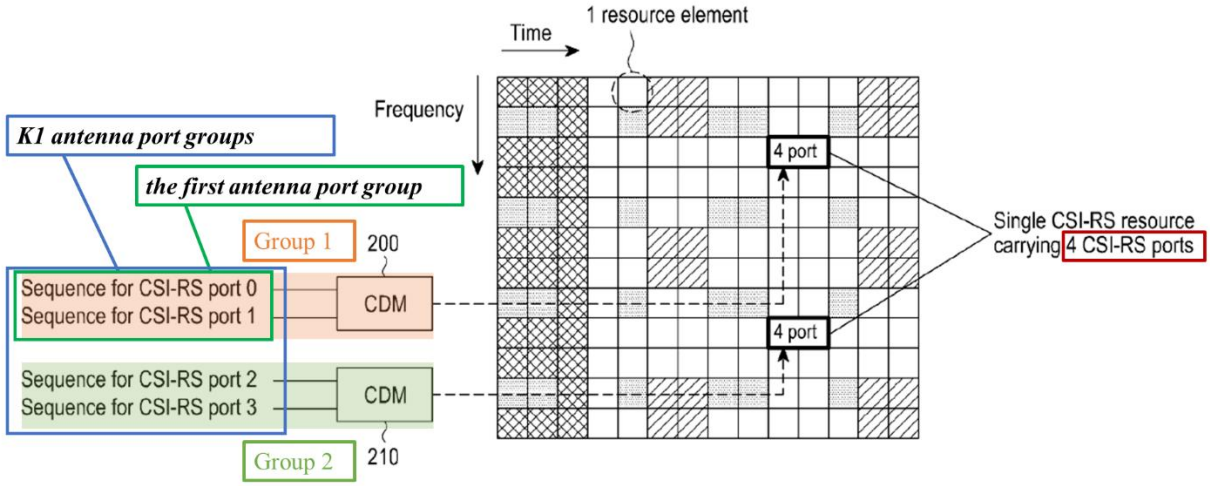


FIG.2
(RELATED ART)

APPLE-1004, FIG. 2.

[4.2] or, transmitting second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer; the second information includes a CRI(CRIs) (CSI-RS Resource Indicator), and the CRI(s) indicates(indicate) the CSI-RS resource(s) corresponding to the K1 antenna port group(s) from the CSI-RS resources corresponding to the K antenna port groups;

149. Element [4.2] is separated by an "or" and thus, satisfying element [4.1] satisfies all of claim 4.

> ***[4.3] or, transmitting second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer; the second information is a RACH preamble, and at least one of the sequence of the RACH preamble or the time-frequency resource occupied by the RACH preamble is used to determine the first antenna port group.***

150. Element [4.3] is separated by an "or" and thus, satisfying element [4.1] satisfies all of claim 4.

5. Claim 5

> ***[5.0] The method of claim 1, wherein the first time resource pool is discontinuous in time domain; or the first signaling is a semi-static signaling; or the first signaling is a high layer signaling; or the first signaling is a physical layer signaling; or the first signaling includes one or more RRC IEs; or the first signaling is carried by a PDCCH; or the first signaling is transmitted on a PBCH; or the first signaling is cell-common; or the first signaling is for the UE.***

151. The Combination renders obvious [5.0]. For example, Kim discloses several of the elements in [5.0] which are each separated by "or" and thus satisfying only one element will satisfy [5.0].

152. First, a POSITA would have understood and found obvious that the first signaling of [1.3] or the SIB assigned time resources, for example through TDD. APPLE-1004, 0062-0079, FIG. 9, 12 (showing alternating uplink and downlink subframes). Thus, in various configurations of TDD, ***the first time***

resource pool is discontinuous in time domain as demonstrated by Dahlman's figure 9.7 where the downlink subframes (collectively the ***first time resource pool)*** are separated into periods separated by uplink subframes and is thus the collection of downlink subframes are ***discontinuous in the time domain.***

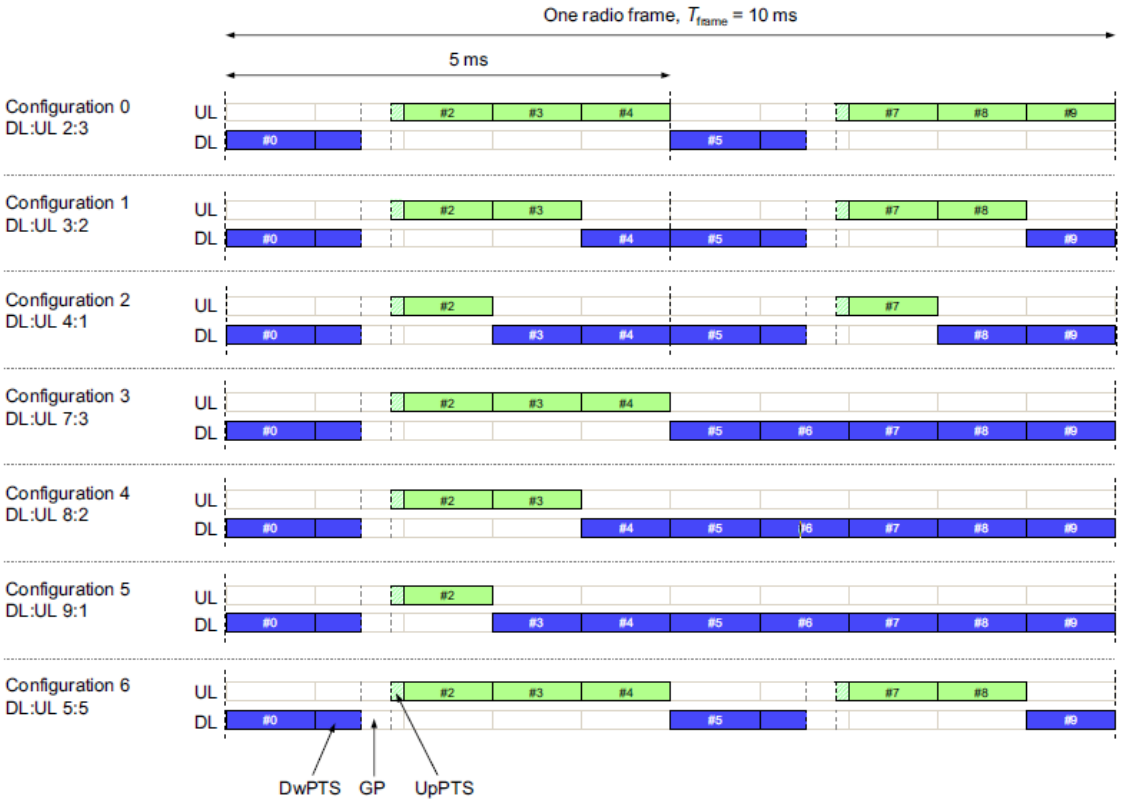


FIGURE 9.7

Different downlink/uplink configurations in case of TDD

APPLE-1007, FIG. 9.7

153. Second, Kim teaches that the ***first signaling is for the UE*** because the SIB (***first signaling***) provides "information that terminals [UEs] need in order to be able to access the cell." APPLE-1007, 359.

6. Claim 6

[6.1] A method for multi-antenna transmitting in a base station, comprising:

154. *See* [1.1] (explaining communication between a base station and UE).

[6.2] transmitting a first radio signal; and

155. Where [1.2] references "receiving," Kim also teaches ***transmitting*** from the base station. *See* [1.2]; APPLE-1004, 0050("(eNB)) 300 transmits a wireless signal through scores or more transmission antennas."), FIG. 3.

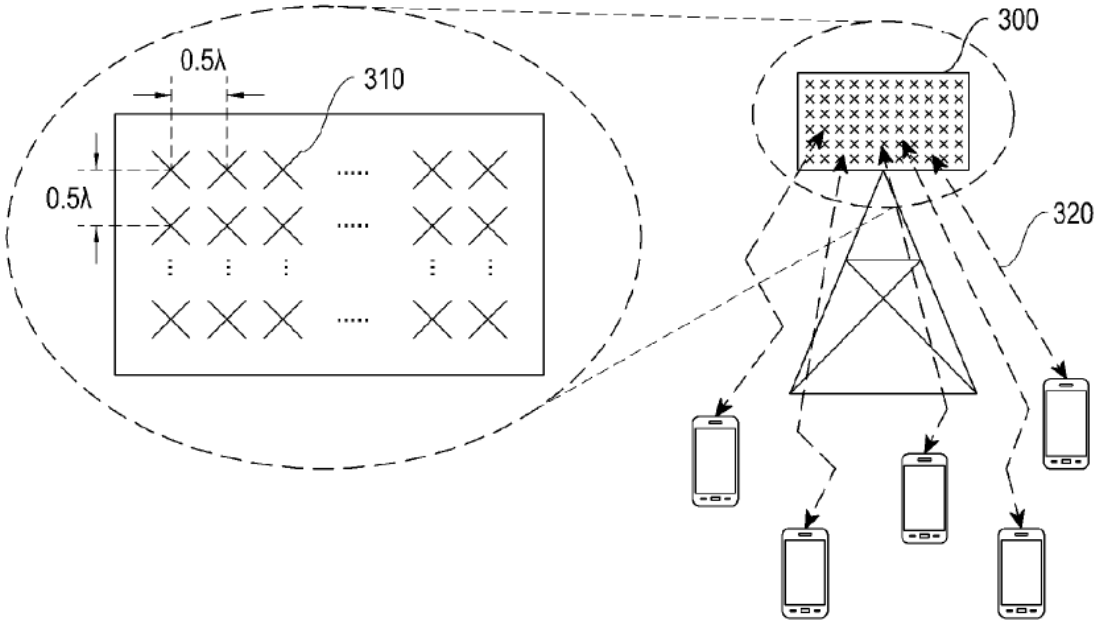


FIG.3

APPLE-1004, FIG. 3.

[6.3] transmitting a first signaling;

156. *See* [6.2], [1.3].

[6.4] wherein the first radio signal is transmitted by K antenna port groups; the antenna port group includes a positive integer number of antenna port(s);

157. *See* [1.4].

[6.5] a first antenna port group is one of the K antenna port groups;

158. *See* [1.5].

[6.6] the first signaling is used to determine a first time resource pool;

159. *See* [1.6].

[6.7] a second antenna virtualization vector is associated with the first antenna port group;

160. *See* [1.7].

[6.8] the second antenna virtualization vector is an antenna virtualization vector available to a target receiver of the first signaling in the first time resource pool; and

161. *See* [1.8]. A POSITA would have understood and found obvious that a ***target receiver of the first signaling*** is a UE. APPLE-1004, 0050("(eNB)) 300 transmits a wireless signal through scores or more transmission antennas."), FIG. 3.

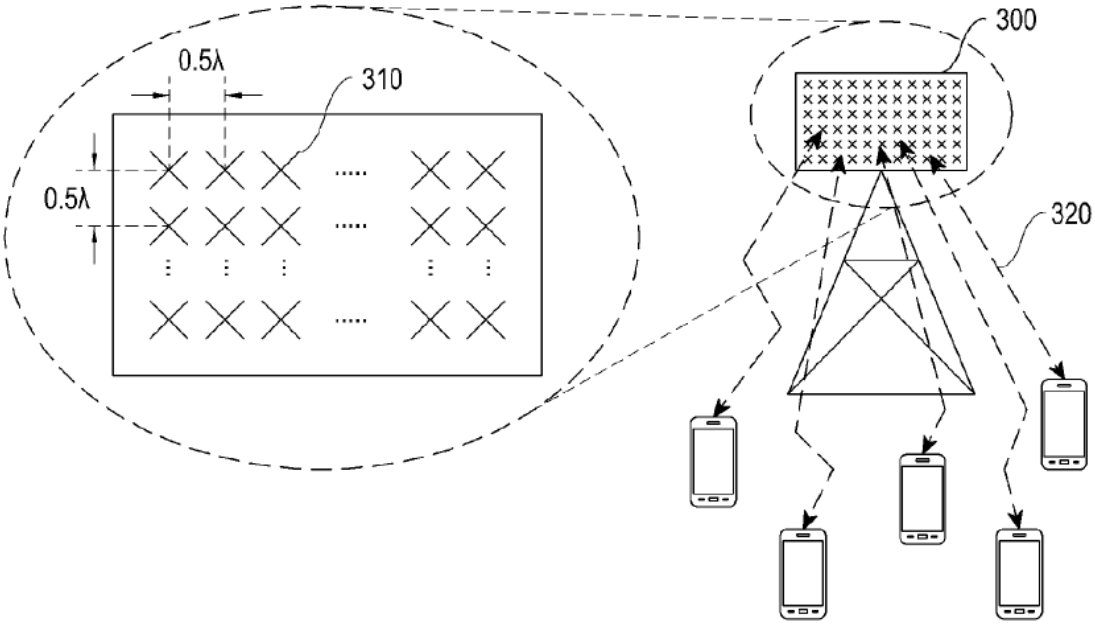


FIG.3

APPLE-1004, FIG. 3.

[6.9] the K is a positive integer greater than 1;

162. *See* [1.9].

[6.10] the first radio signal includes one or more of PSS (Primary Synchronization Signal), SSS (Secondary Synchronization Signal), MIB (Master Information Block)/SIB (System Information Block) or CSI-RS (Channel State Information Reference signal);

163. *See* [1.10].

[6.11] the first signaling is a downlink signaling.

164. *See* [1.11].

7. Claim 7

[7.1] The method of claim 6, further comprising: transmitting a second signaling; and

165. Where [2.1] references "receiving," Kim also teaches ***transmitting*** from the base station. *See* [2.1].

[7.2] performing a second radio signal in a first time resource sub-pool;

166. Where [2.2] references "operating," and [2.3] requires the "operating" to be "receiving," and a POSITA would have understood and found obvious, that ***performing*** and "operating" a transmission from the base station are synonymous. *See* [2.2], [7.3](where performing is transmitting). A POSITA would have understood and found obvious that the MIMO system of the Combination renders obvious **performing** because the UE and base station both transmit and receive.

[7.3] wherein the performing is one of transmitting or receiving the second radio signal;

167. *See* [2.3].

[7.4] the second signaling is used to determine the first time resource sub-pool from the first time resource pool;

168. *See* [2.4].

[7.5] the second signaling is used to determine at least one of occupied frequency domain resources, an MCS, a HARQ process number, an RV, an NDI and (a) transmitting antenna port(s) of the second radio signal.

169. *See* [2.5].

8. Claim 8

[8.1] The method of claim 6, wherein the first signaling indicates the first antenna port group from the K antenna port group(s);

170. *See* [3.1].

[8.2] or, comprising: transmitting first information, wherein the first information is used to determine the first antenna port group.

171. Where [3.2] references "receiving," Kim also teaches ***transmitting*** from the base station. *See* [3.2].

9. Claim 9

[9.1] The method of claim 6, further comprising: receiving second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer;

172. Where [4.1] references "receiving," Kim also teaches ***transmitting*** from the base station. *See* [4.1].

[9.2] or, receiving second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer; the second information includes a CRI(CRIs) (CSI-RS Resource Indicator), and the CRI(s) indicates(indicate) the CSI-RS resource(s) corresponding to the K1 antenna port group(s) from the CSI-RS resources corresponding to the K antenna port groups;

173. *See* [4.2].

[9.3] or, receiving second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer; the second information is a RACH preamble,

and at least one of the sequence of the RACH preamble or the time-frequency resource occupied by the RACH preamble is used to determine the first antenna port group.

174. *See* [4.3].

10. Claim 10

[10] The method of claim 6, wherein the first time resource pool is discontinuous in time domain; or the first signaling is a semi-static signaling; or the first signaling is a high layer signaling; or the first signaling is a physical layer signaling; or the first signaling includes one or more RRC IEs; or the first signaling is carried by a PDCCH; or the first signaling is transmitted on a PBCH; or the first signaling is cell-common; or the first signaling is for the UE.

175. *See* [5].

11. Claim 11

[11.1] A user equipment (UE) for multi-antenna transmission, comprising:

176. *See* [1.1].

[11.2] a first transceiver, receiving a first radio signal; and

177. The Combination renders obvious [11.2]. Specifically, a POSITA would have understood and found obvious that a UE (e.g., a mobile device communication with a transmission tower base station) would utilize a transceiver operably connected to the antennas of the MIMO device. APPLE-1004, 0007 ("receiver and transmitter"), 0020, 0050, FIG. 14-15, cl. 20; *See* [1.2].

[11.3] a second receiver, receiving a first signaling;

178. The Combination renders obvious the use of multiple receivers.

APPLE-1004, 0132, FIG. 15; *See* [11.2], [1.3].

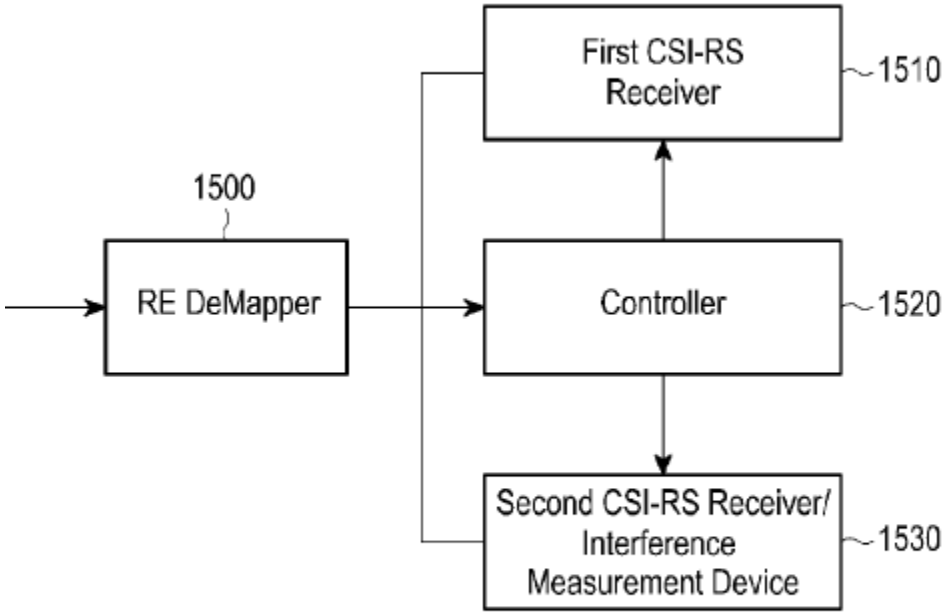


FIG.15

APPLE-1004, FIG. 15.

[11.4] wherein the first radio signal is transmitted by K antenna port groups; the antenna port group includes a positive integer number of antenna port(s);

179. *See* [1.4].

[11.5] a first antenna port group is one of the K antenna port groups;

180. *See* [1.5].

[11.6] the first signaling is used to determine a first time resource pool;

181. *See* [1.6].

[11.7] a second antenna virtualization vector is associated with the first antenna port group;

182. *See* [1.7].

[11.8] the second antenna virtualization vector is an antenna virtualization vector available to the user equipment in the first time resource pool; and

183. *See* [1.8].

[11.9] the K is a positive integer greater than 1;

184. *See* [1.9].

[11.10] the first radio signal includes one or more of PSS (Primary Synchronization Signal), SSS (Secondary Synchronization Signal), MIB (Master Information Block)/SIB (System Information Block) or CSI-RS (Channel State Information Reference signal);

185. *See* [1.10].

[11.11] the first signaling is a downlink signaling.

186. *See* [1.11].

12. Claim 12

[12.1] The UE of claim 11, comprising: a third receiver, receiving a second signaling; and

187. The Combination teaches and a POSITA would have understood and found obvious that in a MIMO system, some devices would contain multiple transceivers. APPLE-1004, 0132, FIG. 15; *see* [11.3], [2.1].

[12.2] a second transceiver, operating a second radio signal in a first time resource sub-pool;

188. APPLE-1004, 0132, FIG. 15; *see* [11.3], [12.2], [2.2].

[12.3] wherein the operating is one of receiving or transmitting the second radio signal;

189. *See* [2.3].

[12.4] the second signaling is used to determine the first time resource sub-pool from the first time resource pool; and

190. *See* [2.4].

[12.5] the second signaling is used to determine at least one of occupied frequency domain resources, a MCS, a HARQ process number, a RV, a NDI and (a) transmitting antenna port(s) of the second radio signal.

191. *See* [2.5].

13. Claim 13

[13.1] The UE of claim 11, wherein the first signaling indicates the first antenna port group from the K antenna port group(s);

192. *See* [3.1], [12.1].

[13.2] or, the second receiver further receives first information, wherein the first information is used to determine the first antenna port group.

193. *See* [3.2], [12.1].

14. Claim 14

[14.1] The UE of claim 11, wherein: the first transceiver further transmits second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer;

194. *See* [4.1], [12.1].

[14.2] or, the first transceiver further transmits second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer; the second information includes a CRI(CRIs) (CSI-RS Resource Indicator), and the CRI(s) indicates(indicate) the CSI-RS resource(s) corresponding to the K1 antenna port group(s) from the CSI-RS resources corresponding to the K antenna port groups;

195. *See* [4.2], [12.1].

[14.3] or, the first transceiver further transmits second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer; the second information is a RACH preamble, and at least one of the sequence of the RACH preamble or the time-frequency resource occupied by the RACH preamble is used to determine the first antenna port group.

196. *See* [4.3], [12.1].

15. Claim 15

[15] The UE of claim 11, wherein the first time resource pool is discontinuous in time domain; or the first signaling is a semi-static signaling; or the first signaling is a high layer signaling; or the first signaling is a physical layer signaling; or the first signaling includes one or more RRC IEs; or the first signaling is carried by a PDCCH; or the first signaling is transmitted on a PBCH; or the first signaling is cell-common; or the first signaling is for the UE.

197. *See* [5].

16. Claim 16

[16.1] A base station equipment for multi-antenna transmission, comprising:

198. *See* [1.1], [6.1].

[16.2] a third transceiver, transmitting a first radio signal; and

199. *See* [1.2], [12.1].

[16.3] a second transmitter, transmitting a first signaling;

200. *See* [1.3], [12.1].

[16.4] wherein the first radio signal is transmitted by K antenna port groups; the antenna port group includes a positive integer number of antenna port(s);

201. *See* [1.4].

[16.5] a first antenna port group is one of the K antenna port groups;

202. *See* [1.5].

[16.6] the first signaling is used to determine a first time resource pool;

203. *See* [1.6].

[16.7] a second antenna virtualization vector is associated with the first antenna port group;

204. *See* [1.7].

[16.8] the second antenna virtualization vector is an antenna virtualization vector available to a target receiver of the first signaling in the first time resource pool; and

205. *See* [1.8].

[16.9] the K is a positive integer greater than 1;

206. *See* [1.9].

[16.10] the first radio signal includes one or more of PSS (Primary Synchronization Signal), SSS (Secondary Synchronization Signal), MIB (Master Information Block)/SIB (System Information Block) or CSI-RS (Channel State Information Reference signal);

207. *See* [1.10].

[16.11] the first signaling is a downlink signaling.

208. *See* [1.11].

17. Claim 17

[17.1] The base station equipment of claim 16, further comprising: a third transmitter, transmitting a second signaling; and

209. *See* [2.1], [11.2]-[11.3], [12.1].

[17.2] a fourth transceiver, performing a second radio signal in a first time resource sub-pool;

210. *See* [2.2], [11.2]-[11.3], [12.1].

[17.3] wherein the performing is one of transmitting or receiving the second radio signal;

211. *See* [2.3], [12.1].

[17.4] the second signaling is used to determine the first time resource sub-pool from the first time resource pool;

212. *See* [2.4], [12.1].

[17.5] the second signaling is used to determine at least one of occupied frequency domain resources, a MCS, a HARQ process number, a RV, a NDI and (a) transmitting antenna port(s) of the second radio signal.

213. *See* [2.5], [12.1].

18. Claim 18

[18.1] The base station equipment of claim 16, wherein the first signaling indicates the first antenna port group from the K antenna port group(s);

214. *See* [3.1], [12.1].

[18.2] or, the second transmitter further transmits first information, wherein the first information is used to determine the first antenna port group.

215. *See* [3.2], [12.1].

19. Claim 19

[19.1] The base station equipment of claim 16, wherein: the third transceiver further receives second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer;

216. *See* [4.1], [12.1].

[19.2] or, the third transceiver further receives second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer; the second information includes a CRI(CRIs) (CSI-RS Resource Indicator), and the CRI(s) indicates(indicate) the CSI-RS resource(s) corresponding to the K1 antenna port group(s) from the CSI-RS resources corresponding to the K antenna port groups;

217. *See* [4.2], [12.1].

[19.3] or, the third transceiver further receives second information, wherein the second information is used to determine K1 antenna port group(s); the K1 antenna port group(s) belong(s) to the K antenna port groups; the first antenna port group is one of the K1 antenna port group(s); the K1 is a positive integer; the second information is a RACH preamble, and at least one of the sequence of the RACH preamble or the time-frequency resource occupied by the RACH preamble is used to determine the first antenna port group.

218. *See* [4.3], [12.1].

20. Claim 20

[20] The base station equipment of claim 16, wherein the first time resource pool is discontinuous in time domain; or the first signaling is a semi-static signaling; or the first signaling is a high layer signaling; or the first signaling is a physical layer signaling; or the first signaling includes one or more RRC IEs; or the first signaling is carried by a PDCCH; or the first signaling is transmitted on a PBCH; or the first signaling is cell-common; or the first signaling is for the UE.

219. *See* [5].

X. CONCLUSION

220. For all the reasons I have noted in the foregoing paragraphs, claims 1-20 of the ‘110 Patent are obvious in view of the references discussed above.

221. I currently hold the opinions set expressed in this declaration. But my analysis may continue, and I may acquire additional information and/or attain supplemental insights that may result in added observations.

APPENDIX A

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Narayan B. Mandayam is a Distinguished Professor and Chair of Electrical and Computer Engineering at Rutgers University, where he also serves as Associate Director of the Wireless Information Network Laboratory (WINLAB). Using constructs from game theory, communications and networking, his work has focused on system modeling, information processing as well as resource management for enabling cognitive wireless technologies to support various applications. His recent interests include enabling privacy in IoT, building resilience in smart city infrastructures, machine learning for enhancing physics based models, as well as modeling and analysis of trustworthy knowledge creation on the internet. His recent work has also focused on the use of prospect theory in understanding the psychophysics of end-user behavior in wireless data networks as well as the smart grid. Dr. Mandayam is a recipient of the *2015 IEEE Communications Society Advances in Communications Award* (given to the most impactful paper in the preceding 15 calendar years) for his work on power control and pricing, the *2014 IEEE Donald G. Fink Award* for his IEEE Proceedings paper titled Frontiers of Wireless and Mobile Communications and the *2009 Fred W. Ellersick Prize* from the IEEE Communications Society for his work on dynamic spectrum access models and spectrum policy. He is also a recipient of the Peter D. Cherasia Faculty Scholar Award from Rutgers University (2010), the National Science Foundation CAREER Award (1998), the Institute Silver Medal from the Indian Institute of Technology, Kharagpur (1989) and its Distinguished Alumnus Award (2018). He is an IEEE Fellow and Distinguished Lecturer.

EDUCATION:

Ph. D in Electrical Engineering, May 1994
Rice University, Houston, Texas

M.S. in Electrical Engineering, May 1991
Rice University, Houston, Texas

B. Tech (Hons.) in Electrical Engineering, May 1989
Indian Institute of Technology, Kharagpur, India

EXPERIENCE:

Dept. of ECE, Rutgers University, *Piscataway, New Jersey*
Department Chair, July 2016 - present

Distinguished Professor, July 2014- present

Peter D. Cherasia Endowed Faculty Scholar, June 2010 - June 2014

Professor, July 2003 - June 2014

Associate Professor, July 2001 - June 2003

Assistant Professor, July 1996 - June 2001

WINLAB, Dept. of ECE, Rutgers University, *Piscataway, New Jersey*
Interim Director, January 2001 - July 2001

Associate Director, December 1999 - present

Research Associate, Sep. 1994 - June 1996

Princeton University, *Princeton, New Jersey*
Faculty Fellow in Dept. of EE, Sep. 2002 - Dec. 2002

Indian Institute of Science, *Bangalore, India*
Visiting Faculty in Dept. of ECE, Jan. 2003 - Jun. 2003

AWARDS AND HONORS:

- *Distinguished Alumnus Award* from the Indian Institute of Technology (IIT), Kharagpur (2018)
- *Big Ten Academic Alliance (BTAA) Department Executive Officers (DEO) Fellow* – one of 5 Department Chairs selected from over a 100 at Rutgers (2017)
- *Advances in Communication Award* from the IEEE Communications Society (2015) – highest ("test of time") paper award of IEEE COMSOC; awarded to the most impactful paper in any IEEE COMSOC publication over the preceding 15 calendar years
- *Donald G. Fink Award* from the IEEE (2014) - highest paper award across all IEEE Publications in the preceding calendar year
- *National Academies Keck Futures Initiative (NAKFI) Grant Award* (2013)- "From Informed Human Brains to Society-Scale Silicon Brains: Uncovering the DNA of Social Knowledge"
- Invitee to *National Academies Keck Futures Initiative (NAKFI) Informed Brain in a Digital World* (one of 100 invitees in the U.S. selected by the National Academy of Engineering (NAE), National Academy of Sciences (NAS), and Institute of Medicine (IOM)) (2012)
- *Distinguished Lecturer* of the IEEE (2012-15)
- *Peter D. Cherasia Faculty Scholar Award*, Rutgers University (2010)
- Technical Program Co-Chair, WiOPT (2011)
- Briefer to JASON (an elite advisory group to the U.S. government) study on Cognitive Radio Networks (2010)
- *Fred W. Ellersick Prize* from the IEEE Communications Society (2009) for the best paper in a IEEE Communications Society Magazine in the preceding 3 calendar years
- Fellow, IEEE for contributions to "Wireless Data Transmission" (2009)
- Guest Editor, IEEE JSAC - Game Theory in Communications and Networking (2008)
- Guest Editor, IEEE JSAC - Spectrum Agile Cognitive Radio Networks (2007)
- Editor, IEEE Transactions on Wireless Communications (2002-2005)
- Outstanding Engineering Faculty Recognition, Rutgers University (2000)
- Associate Editor, IEEE Communications Letters (1999-2003)
- Invitee to *Annual Symposium on Frontiers of Engineering*, National Academy of Engineering (NAE) (one of hundred engineers in the U.S. selected by the NAE) (1999)
- National Science Foundation (NSF) CAREER Award (1998)
- *Outstanding Branch Counselor and Advisor Award Nominee*, IEEE (1998-99)
- *William Marsh Rice Fellowship*, Rice University (1989-1990)
- *Institute Silver Medal*, Indian Institute of Technology (I.I.T.), Kharagpur (Awarded to the graduating student with the highest G.P.A. in Electrical Engineering) (1989)
- *National Talent Search Scholarship* Awarded by the National Council of Educational Research and Training, New Delhi, India (1983-1989)

CURRENT RESEARCH INTERESTS:

- Machine Learning for Enhancing Physics Based Models
- Resilience in Smart Cities
- 5G and Beyond 5G Networks
- Reality Aware Networks
- Prospect Theory in the Design of Cyberphysical Systems
- Privacy and Security for Internet of Things
- Resource Allocation in Wireless Networks using Non Radio Attributes
- Energy Efficient Internet of Things
- End-User Behavior and the Smart Grid
- Microeconomics of Information Centric Networks
- Noncontiguous Spectrum Access and Software Defined Networks
- Modeling of Social Knowledge Creation

GRANTS: (PI or co-PI on $\sim$ $42M funding from Federal, State and Industry Sources)

1. "Standalone Mobile Core Network (SA-MCN) Architecture and Enabling Technologies- Phase II," US Department of Defense Contract ($1,315,000), October 2020; PI: Narayan Mandayam, co-PI: Dipankar Raychaudhuri, Ivan Seskar
2. "EAGER: SARE: Directional Modulation Non-Contiguous OFDM Retrodirective Communication for Secure IoT," National Science Foundation Grant ($300,000), September 2020; PI: Chung-Tse Michael Wu, co-PI: Narayan Mandayam, Waheed Bajwa
3. "SII Planning: ARIES: Center for Agile, RelIablE, Scalable Spectrum," National Science Foundation Grant ($300,000), August 2020; PI: Walid Saad, co-PI: Narayan Mandayam, Douglas Sicker, Andreas Molisch, Harpreet Dhillon
4. "Standalone Mobile Core Network (SA-MCN) Architecture and Enabling Technologies," US Department of Defense Contract ($450,000), August 2019; PI: Narayan Mandayam, co-PI: Dipankar Raychaudhuri, Ivan Seskar
5. "Reality-Aware Networks" National Science Foundation Grant ($800,000), April 2018; PI: Marco Gruteser, co-PI: Kristin Dana, Narayan Mandayam (Rutgers is the lead institution in collaboration with Old Dominion University and Georgia State University).
6. "COSMOS: Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment" National Science Foundation Grant ($12.5M), April 2018; PI: Dipankar Raychaudhuri, co-PI: Marco Gruteser, Narayan Mandayam, Thu Nguyen, Ivan Seskar (Rutgers is the lead institution in collaboration with Columbia University and NYU)
7. "EAGER: SSDIM: Simulated and Synthetic Data for Interdependent Communications and Energy Critical Infrastructures" National Science Foundation Grant ($100,000), September 2017; PI: Narayan Mandayam, co-PI: Arnold Glass, Janne Lindqvist
8. "TWC: PERMIT: Privacy-Enabled Resource Management for IoT Networks" National Science Foundation (NSF) Grant No.1617849 ($500,000), September 2016; - PI: Anand Sarwate, co-PI: Narayan Mandayam
9. "Towards Resilient Smart Cities" National Science Foundation CRISP Grant No. 1541069 ($900,000), January 2016; PI: Narayan Mandayam, co-PI: Janne Lindqvist, Arnold Glass
10. "EAGER: Renewables: Foundations of Prosumer-Centric Grid Energy Management" National Science Foundation Grant ($100,000), October 2015; PI: Narayan Mandayam, co-PI: Arnold Glass
11. "A Software Defined Framework for Opportunistic Networking and Spectrum Management" Office of Naval Research (ONR) Grant ($1,000,000), January 2015; PI: Narayan Mandayam, co-PI: Ivan Seskar, S. Kompella (NRL)
12. "NeTS: End-User Behavior and Prospect Pricing in Wireless Data Networks" National Science Foundation (NSF) Grant No. 1421961 ($500,000), October 2014; - PI: Narayan Mandayam, co-PI: Arnold Glass (Rutgers Psychology)
13. "NeTS: Transmit Only: Green Communication for Dense Wireless Systems" National Science Foundation (NSF) Grant No.1423020 ($498,000), October 2014; - PI: Yanyong Zhang, co-PI: Narayan Mandayam
14. " From Informed Human Brains to Society-Scale Silicon Brains: Uncovering the DNA of Social Knowledge" NAKFI Grant Award ($ 50,000), May 2013, PI: Oded Nov, co-PI: Narayan Mandayam, Ofer Arazy
15. "NeTS: Visual MIMO Networks" National Science Foundation (NSF) Grant No. CNS-1065463 ($ 685,000), April 2011; - PI: Marco Gruteser, co-PI: Narayan Mandayam, Kristin Dana
16. "Bandwidth Exchange: A Framework for Enhancing the Performance of Cognitive Radio Networks" Office of Naval Research (ONR) ($ 300,000), February 2011; - PI: Narayan Mandayam
17. "DEDI: A New Framework for the Practice of Wireless Network Coding" National Science Foundation (NSF) CIF Grant ($ 427,000), September 2010; - PI: Narayan Mandayam

18. “MIAMI: Mobile Infrastructures for Advancing Military Information Technologies” US Army-TACOM-ARDEC ($ 659,401), September 2009; - PI: Wade Trappe, co-PI: Narayan Mandayam, D. Raychaudhuri, I. Seskar
19. “RF Equipment Upgrades to Enable Scalable Crosslayer Protocol Experimentation on the ORBIT Radio Grid Testbed” Army Research Office ($ 65,000), September 2008; - PI: Wade Trappe, co-PI: Narayan Mandayam
20. “NeTS-WN: A Joule for your Byte: Barter-Exchange Incentive Mechanisms for Wireless Networks” National Science Foundation (NSF) Grant No. CNS-0721826 ($ 450,000), September 2007; - PI: Roy Yates, co-PI: Narayan Mandayam
21. “Cooperation and Conflict - Coalitional Games in Spectrum Sharing” National Science Foundation (NSF) Theoretical Foundations Grant, CCF-0634973($ 100,000), September 2006; - PI: Narayan Mandayam
22. “Fingerprints in the Ether - Exploiting the Radio Channel to Enhance Wireless Security” National Science Foundation (NSF) NeTS-ProWiN Grant ($581,332), September 2006; - PI: Wade Trappe, co-PI: Narayan Mandayam, Larry Greenstein
23. “Cog-Net- An Experimental Protocol Stack for Cognitive Radio Networks and its Interaction with the Future Internet” National Science Foundation (NSF) NeTS-FIND Grant ($450,000), September 2006; - PI: Dipankar Raychaudhuri, co-PI: Narayan Mandayam, Predrag Spasojevic
24. “NeTS-Cognitive Radios for Enabling Open Access to Spectrum” National Science Foundation (NSF) Grant No. NeTS-0434854 ($ 670,000), September 2004; - PI: Narayan Mandayam, Co-PI : Chris Rose, Predrag Spasojevic, Roy Yates
25. “FMF-Unquantized and Uncoded Channel State Feedback in Multiple Antenna Multiuser Wireless Systems” National Science Foundation (NSF) Grant No. 0429724($ 200,000), September 2004; - PI: Narayan Mandayam
26. ”Center for Multimodal Wireless Integrated Sensor-On-Silicon (MUSE) Technology” New Jersey Commission on Science and Technology ($2,820,000)) September 2002; - PI: Dipankar Raychaudhuri, Co-PIs : Yicheng Lu, Narayan Mandayam, John Li, Joseph Kedem
27. ”Wireless Instructional Lab and Curriculum Development” Intel Corporation ($ 240,000) September 2002; -PI: Narayan Mandayam, Co-PI : Dipankar Raychaudhuri, Badri Nath
28. “Achieving Innovative and Reliable Services in Unlicensed Spectrum” National Science Foundation (NSF) ITR Grant No. 0205362($ 886,411), September 2002; - PI: Roy Yates, Co-PI : Narayan Mandayam, Dipankar Raychaudhuri, Chris Rose, Predrag Spasojevic
29. “”Free Bits” : The Real Challenge of the Wireless Internet” National Science Foundation (NSF) ITR Grant No. 0085986 ($ 860,000), September 2000; - PI: Roy Yates, Co-PI : Narayan Mandayam, Chris Rose
30. “CAREER: Radio Resource Management for Wireless Data Networks” National Science Foundation (NSF) Career Grant CCR-9874976 ($ 200,001) September 1, 1999; - PI : Narayan Mandayam
31. “Media Access Control (MAC) Protocols for Wireless Multimedia CDMA Systems” Telcordia Technologies ($ 10,000) September 1, 1999; -PI: Narayan Mandayam
32. “Performance Analysis of Interference Cancellation for WCDMA Systems in Multicell Environments” NTT DoCoMo, Japan ($ 90,000) September 1, 1999; - PI: Roy Yates, Co-PI : Narayan Mandayam
33. “KDI: Multimodal Collaboration Across Wired and Wireless Networks” National Science Foundation (NSF) IIS-98-72995 ($ 2,196,006) September 1, 1998; - PI: Jim Flanagan, Co-PIs : Narayan Mandayam, David Goodman, Casimir A. Kulikowski, Sven J. Dickinson, Ivan Marsic, Peter Meer, Manish Parashar
34. “Digital Radio as Enabling Technology for Computing, Communications and Information Systems” New Jersey Commission on Science and Technology ($1,218,405) July 1998; - PI: Roy Yates, Co-PIs : Richard Frenkiel, Narayan Mandayam and Chris Rose

35. "Parallel Computing For Wireless Networking Research" National Science Foundation (NSF) NCR 97-29863 ($ 170,000) November 1, 1997; - PI: David Goodman, Co-PIs : Narayan Mandayam, Andrew Ogielski, Christopher Rose and Roy Yates
36. " Capacity and Protocols for Integrated Voice/Data CDMA Systems" National Science Foundation (NSF) NCR 97-06036 ($ 328,057) October 1, 1997; - PI : Narayan Mandayam
37. "Scalable Self-Organizing Simulations S3" DARPA ITO Order No. AOD 812, Contract No. N66001-96-C-8530 (Contract Issued by -: Naval Command Control and Ocean Surveillance Center (NCCOSC)) 1997-1999 (Rutgers Internal Grant ($ 504,225) administered by Center for Discrete Mathematics and Theoretical Computer Science (DIMACS)) - PI : Narayan Mandayam, Co-PI: Roy Yates
38. "Subspace-based Approaches for Signal Quality Estimation and Interference Cancelation in Wireless Systems" Texas Instruments Inc. ($ 33,500) September 1, 1997; - PI: Narayan Mandayam, Co-PI : Roy Yates
39. "Interference Cancellation Prototyping and ASIC Development for Wireless CDMA Communication" National Science Foundation (NSF), NSF IUCRC for Wireless Information Networks : TIE Program between University of California San Diego and The State University of New Jersey ($50,000) August 15, 1997; Rutgers University (PI: Narayan Mandayam) UC San Diego (PI: Paul Chau)
40. "A Testbed for Multiuser Detection" Office of Naval Research (ONR) ($ 119,000) January 1, 1997; PI : Narayan Mandayam
41. "Capacity and Protocols for Multimedia Wireless Systems" AT & T Foundation Grant, ($ 23,400) January 1, 1997; PI : Narayan Mandayam, Co-PI: David Goodman

INVITED TALKS:

- *"Resilience in Smart Cities"* Stevens Institute of Technology, NJ, October 2020
- *"Resilience in Smart Cities"* Lehigh University, PA, February 2020
- *"Resilience in Smart Cities"* Indian Institute of Technology (IIT)-Hyderabad, India, January 2020
- *"Resilience in Smart Cities"* Drexel University, Philadelphia, PA, March 2019
- *"Resilience in Smart Cities"* IEEE Princeton Jersey Section, Princeton, NJ, December 2018
- *"Resilience in Smart Cities"* University of Electronics Science and Technology (UESTC), Chengdu, China, July 2018
- *"Resilience in Smart Cities"* Keynote at 60th Anniversary of Computer Science at Tsinghua University, Beijing, China, July 2018
- *"Resilience in Smart Cities"* Keynote at IEEE Sarnoff Symposium, NJ September 2017
- *"Dynamic Spectrum Access in 5G: What's new?"* ECE Colloquium, University of Illinois at Urbana-Champaign, November 2016
- *"Backhauling in TV White Space using LTE-U"* IEEE Distinguished Lecture, NJ Coast Section, Holmdel, NJ, November 2015
- *"Game Theoretic Modeling of Online Knowledge Creation in Wikipedia"* ITA Workshop, San Diego, CA, February 2015
- *"Backhauling in TV White Space"* New Jersey Advanced Communications Symposium, Hoboken, NJ September 2014
- *"Towards Uncovering the DNA of Silicon Brains"* SEEDS Seminar, University of Miami, Miami, FL, April 2014
- *"Forces and Strategies that Shaped the Wireless Revolution"* Bell Labs, Alcatel-Lucent, Bangalore, July 2013
- *"Backhauling in TV White Spaces"* IEEE Distinguished Lecture, Indian Institute of Science (IISc.), Bangalore, India, July 2013
- *"When Users Interfere with Protocols - Prospect Theory in Wireless Networks"* IEEE Communication Theory Workshop, Phuket, Thailand, June 2013
- *"Towards Green Techniques for Wireless Networks"* IEEE Distinguished Lecture, University of Technology, Kingston, Jamaica, May 2013

- *"Network Coding as a Dynamical System"* IEEE Distinguished Lecture, IEEE COMSOC, Orlando, FL, May 2013
- *"Backhauling in TV White Spaces"* IEEE Distinguished Lecture,Adtran Corp., Huntsville, AL, May 2013
- *"Forces and Strategies that Shaped the Wireless Revolution"* IEEE Distinguished Lecture, AT&T, Birmingham, AL, May 2013
- *"Backhauling in TV White Spaces"* IEEE Distinguished Lecture, Georgia Tech., Atlanta, GA, May 2013
- *"Backhauling in TV White Spaces"* IEEE Distinguished Lecture, IEEE COMSOC, Charleston, SC, May 2013
- *"Backhauling in TV White Spaces"* IEEE Distinguished Lecture, National Electronic Museum, Washington D.C., May 2013
- *"Network Coding as a Dynamical System"* IEEE Distinguished Lecture, Syracuse University, April 2013
- *"Towards Green Techniques for Wireless Networks"* IEEE Distinguished Lecture, Madras Institute of Technology Anna University-KBC, Chennai, India, October 2012
- *"Network Coding as a Dynamical System"* IEEE Distinguished Lecture, Indian Institute of Science (IISc.), Bangalore, India, September 2012
- *"Network Coding as a Dynamical System"* IEEE Distinguished Lecture, Indraprastha Institute of Information Technology (IIIT) Delhi, New Delhi, India, September 2012
- *"Network Coding as a Dynamical System"* IEEE Distinguished Lecture, Osmania University, Hyderabad, India, September 2012
- *"Towards Green Techniques for Wireless Networks"* IEEE Distinguished Lecture, HelloSoft Inc., Hyderabad, India, September 2012
- *"Towards Green Techniques for Wireless Networks"* IEEE Distinguished Lecture, AirTight Networks Inc., Pune, India, September 2012
- *"Towards Green Techniques for Wireless Networks"* IEEE Distinguished Lecture, Institute of Electronics and Telecommunications Engineers (IETE), Pune, India, September 2012
- *"Network Coding as a Dynamical System"* IEEE Distinguished Lecture, Pune University, Pune, India, September 2012
- *"Towards Green Techniques for Wireless Networks"* IEEE Distinguished Lecture, Center for Development of Advanced Computing (C-DAC), Pune, India, September 2012
- *"Enabling Cognitive Radio Networks"* IEEE Distinguished Lecture, Drexel University, Philadelphia, April 2012
- *"Enabling Cognitive Radio Networks"* NSF Workshop on Beyond Cognitive Radio, University of Illinois, Urbana-Champaign, June 2011
- *"Bandwidth Exchange: A Framework for Enhancing the Performance of Cognitive Radio Networks"* Naval Research Laboratories (NRL), Washington D.C., May 2011
- *"Towards Green Techniques for Wireless"* Keynote Address at MedHocNet 2010, Juan-Les-Pins, France, June 2010
- *"Resource Allocation in Cognitive Radio Networks"* JASON Study on Cognitive Radio Networks, San Diego, CA, June 2010
- *"Communicating in TV White Space"* Panel Leader at IEEE Communication Theory Workshop, Cancun, Mexico, May 2010
- *"Towards Green Wireless"* Panelist at IEEE Saranoff Symposium, Princeton, NJ, April 2010
- *"Cognitive Radios in Wireless Ecosystems"* "Workshop on Views on Cognitive Radio: Key Issues and Long-term Development", Huawei Technologies, San Diego, CA, April 2009
- *"Coalitions and Incentives in Cognitive Radio Networks"* New York Metro Area Networking Workshop, Columbia University, New York, March 2009
- *"Coexistence in Cognitive Radio Networks"* NSF Workshop on the Future of Cognitive Radio, Arlington, VA, March 2009
- *"Coalitions and Incentives in Cognitive Radio Networks"* Center for Multimedia Communications Seminar, Rice University, Houston, TX, February 2009
- *"Coalitions and Incentives in Cognitive Radio Networks"* ECE Colloqium, Indian Institute of Science (IISc.), Bangalore, India, October 2008
- *"Coalitions and Incentives in Cognitive Radio Networks"* Illinois Center for Wireless Systems, University of Illinois @ Urbana-Champaign, IL, May 2008

- *"Coalitions and Incentives in Cognitive Radio Networks"* Information Sciences and Systems Seminar, Princeton University, Princeton, NJ, May 2008
- *"Cognitive Radio Networks"* Princeton ACM/IEEE Computer Society Lecture Series, Princeton, NJ, January 2008
- *"Cognitive Radio Networks"* InterDigital Distinguished Lecture, King of Prussia, PA, January 2008
- *"Cognitive Radio Networks"* IEEE Princeton/Central Jersey Communications and Consumer Electronics Lecture Series, Princeton NJ, December 2007
- *"Cognitive Radio Networks"* Electrical Engineering Seminar, Columbia University, New York, September 2007
- *"Cognitive Radio Networks"* National Science Foundation (NSF) Workshop on Bridging Physical Layer and Networking, Reston VA, August 2007
- *"Cognitive Radio Networks"* DIMACS Tutorial on Algorithms for Next Generation Networks, Rutgers University, NJ, August 2007
- *"Cognitive Radio Networks"* ECE Colloqium, Indian Institute of Science (IISc.), Bangalore, India, July 2007
- *"Cognitive Radio Networks- Overview, Challenges and Directions"* Keynote Address at The Frequency Resource Development Symposium, Association of Radio Industries and Businesses, Tokyo, Japan, June 2007
- *"Cognitive Radio Networks- Overview, Challenges and Directions"* National Institute of Information Technology (NICT), Yokosuka, Japan, June 2007
- *"Cognitive Algorithms and Architectures for Open Access to Spectrum"* The Royal Institute of Technology (KTH), Stockholm, Sweden, April 2005
- *"Cognitive Radios for Enabling Open Access to Spectrum"* National Science Foundation (NSF) Wireless Networking PI Meeting, Nashua, NH, October 2004
- *"Freebits: The Real Challenge of the Wireless Internet"* Intel, Bangalore, India, June 2003
- *"Freebits: The Real Challenge of the Wireless Internet"* IEEE Colloquim Series, Bangalore, India, May 2003
- *"Freebits: The Real Challenge of the Wireless Internet"* Defense Research Development Organization (DRDO), Bangalore, India, May 2003
- *"Radio Resource Management for Wireless Data"* Golden Jubilee ECE Colloquim, Indian Institute of Science, Bangalore, India, February 2003
- *"Radio Resource Management for Wireless Data"* Drexel University, Philadelphia, PA January 2002
- *"Radio Resource Management for Wireless Data"* University of California at Irvine, Irvine, July 2001
- *"Free Bits: The Real Challenge of the Wireless Internet"* 3G and Beyond Technology Workshop, Nokia Research Center, Beijing, China, June 2001
- *"Radio Resource Management for Wireless Data"* University of Texas at Dallas, Dallas, May 2001
- *"Radio Resource Management for Wireless Data"* Southern Methodist University, Dallas, April 2001
- *"Power Control for Wireless Data: Static and Dynamic Policies"* IEEE Vehicular Technology Society, North Jersey Chapter Seminar, October 24, 2000
- *"Software Defined Radio Architectures for Interference Cancellation in CDMA Systems"* Morphics Technologies, Campbell, CA, October 13, 2000
- *"Blind Interference Cancellation for CDMA Systems"* Motorola, Piscataway, NJ, September 21, 2000
- *"Power Control for Wireless Data: Static and Dynamic Policies"* Crawford Hill Wireless Coffee Hour Seminar, Bell Labs, Lucent Technologies, August 24, 2000
- *"Power Control for Wireless Data: Static and Dynamic Policies"* Polytechnic University, February 24, 2000
- *"Power Control for Wireless Data: Games, Utility and Pricing"* Newman Springs Seminar, AT & T Research Labs, January 5, 2000
- *"Power Control for Wireless Data: Games, Utility and Pricing"* Princeton University, October 28, 1999
- *"Power Control for Wireless Data: Games, Utility and Pricing"* Columbia University, October

26, 1999

- *"Software Defined Radio Architectures for Interference Cancellation in CDMA Systems"* University of California, San Diego, May 18, 1999
- *"A New Framework for Radio Resource Management in Wireless Data Networks: Games, Utility and Pricing"* New Jersey Institute of Technology, Newark, April 19, 1999
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- *"Wireless Staffing"* Wireless Engineering Roundtable Forum, International Engineering Consortium, Chicago, November 10, 1997
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143. Z. Lei, D. J. Goodman, N. B. Mandayam, "Location Dependent Other-Cell Interference and Its Effect on the Uplink Capacity of a Cellular CDMA System" in *Proceedings of IEEE VTC'99*, pp. 2164-2168, Houston, TX, May 1999

144. Z. Lei, C. Saraydar, N. B. Mandayam, "Dynamic Paging Area Design by Interval Estimation", in the 2nd IEEE Signal Processing Workshop on Signal Processing Advances in Wireless Communications, Annapolis, MD, May, 1999

145. N. Feng, N. B. Mandayam, D. J. Goodman, "Joint Power and Rate Optimization for Wireless Data Services Based on Utility Functions", in *Proceedings of Conference on Information Sciences and Systems, CISS'99*, pp.109-114, The Johns Hopkins University, Baltimore, MD, March 1999

146. J. Lai , N. B. Mandayam, "Performance of Reed-Solomon Codes for Hybrid-ARQ over Rayleigh Fading Channels under Imperfect Interleaving", in *Proceedings of Conference on Information Sciences and Systems, CISS'99*, The Johns Hopkins University, Baltimore, MD, March 1999

147. L. Song, N. B. Mandayam, Z. Gajic "Analysis of an Up/Down Power Control Algorithm for the CDMA Reverse Link: A Nonlinear Control Systems Approach", in *Proceedings of Conference on Information Sciences and Systems, CISS'99*, pp. 119-124, The Johns Hopkins University, Baltimore, MD, March 1999

148. D. Famolari, N. B. Mandayam, D. J. Goodman, "A New Framework for Power Control in Wireless Data Networks: Games, Utility and Pricing", *Proceedings of 36th Annual Allerton Conference on Communication, Control, and Computing*, pp. 546-555, Allerton, IL, September, 1998

149. V. Shah, N.B. Mandayam, D.J. Goodman, "Power Control for Wireless Data based on Utility and Pricing", *Proceedings of PIMRC 1998*, pp. 1427-1432, Boston, September 1998

150. J. Panchal, O. E. Kelly, J. Lai, N. B. Mandayam, A. T. Ogielski, R. D. Yates, " Scalable Parallel Simulations of Wireless Networks with WiPPET: Modeling of Radio Propagation, Mobility and Protocols" *Proceedings of MASCOTS 1998*, Montreal, July 1998

151. I. Seskar, N.B. Mandayam "Reconfigurable Testbed for Linear Multiuser Detection", in *Proceedings of International Conference on Telecommunications (ICT'98)*, Chalkidiki, Greece, June, 1998

152. J. Panchal, O. E. Kelly, J. Lai, N. B. Mandayam, A. T. Ogielski, R. D. Yates, " WIPPET, A Virtual Testbed for Parallel Simulations of Wireless Networks", in *SIGSIM, IEEE-TCSIM, SCS Parallel and Distributed Simulation (PADS'98)*, pp. 162-169, Banff, Canada, May 1998.

153. S. Manji, N.B. Mandayam "Outage Probability for a Zero Forcing Multiuser Detector with Random Signature Sequences" in *Proceedings of IEEE VTC'98*, vol. 1, pp. 174-178, Ottawa, Canada, May, 1998

154. J. Lai, N.B. Mandayam "Packet Error Rate for Burst-Error-Correcting Codes in Rayleigh Fading Channels" in *Proceedings of IEEE VTC'98*, vol. 2, pp. 1568-1572, Ottawa, Canada, May, 1998

155. J. Borras, P. Hatrack, N.B. Mandayam "A Decision Theoretic Framework for NLOS Identification" in *Proceedings of IEEE VTC'98*, vol. 2, pp. 1583-1587, Ottawa, Canada, May, 1998

156. L. Song, N.B. Mandayam "A QoS Based Adaptive Power Control Algorithm for the CDMA Forward Link", in *Proceedings of Conference on Information Sciences and Systems (CISS'98)*, vol. 1, p. 180, Princeton University, Princeton, NJ, March 1998

157. I. Seskar, N.B. Mandayam "A Software Radio Architecture for Linear Multiuser Detection", in *Proceedings of Conference on Information Sciences and Systems (CISS'98)*, vol. 1, pp. 242-247, Princeton University, Princeton, NJ, March 1998

158. J. Lai, N.B. Mandayam "Fade Margins for Minimum Duration Outages in Log-Normal Shadow Fading and Rayleigh Fading" in *Proceedings of Asilomar*, pp. 609-613, Monterrey, CA, November, 1997

159. D. Ramakrishna, N.B. Mandayam, R. Yates "SIR Estimation in CDMA Cellular Systems using Subspace Tracking," in *Proceedings of Asilomar*, pp. 149-153, Monterrey, CA, November, 1997

160. N.B. Mandayam, J. Holtzman "Effect of Tracking Errors on the Coding-Spreading Tradeoff in CDMA Systems" in *Proceedings of ICUPC'97*, vol. 2, pp.366-370, San Diego, CA, October 1997

161. J. Lai, N.B. Mandayam "Minimum Duration Outage for a Cellular System with Rayleigh Fading" in *Proceedings of Conference on Information Sciences and Systems (CISS'97)*, pp. 281-286, The Johns Hopkins University, Baltimore, MD, March 1997

162. A. Sampath, N. B. Mandayam, J. Holtzman "Erlang Capacity of an Integrated Voice/Data CDMA System with Optimal Power Control" in *Proceedings of IEEE VTC'97*, vol. 3, pp. 1557-1561, Phoenix, AZ, May 1997

163. D. Ramakrishna, N.B. Mandayam, R. Yates "Subspace-based Estimation of the Signal-to-Interference Ratio for CDMA Cellular Systems" in *Proceedings of IEEE VTC'97*, vol. 2, pp. 735-739, Phoenix, AZ, May 1997

164. D.J. Goodman, J. Borras, N.B. Mandayam, R. Yates "INFOSTATIONS : A New System Model for Data and Messaging Services" in *Proceedings of IEEE VTC'97*, vol. 2, pp. 969-973, Phoenix, AZ, May 1997

165. D. Ramakrishna, N.B. Mandayam, R. Yates "Subspace based Techniques for Estimation of the Signal-to-Interference Ratio in CDMA Cellular Systems" in *Symposium on Interference Rejection and Signal Separation in Wireless Communications (IRSS'97)*, George Washington University, Washington D.C., March 18, 1997

166. N.B. Mandayam, J. Holtzman "Coding-Spreading Tradeoff in CDMA Systems with Tracking Errors" in *Proceedings of Conference on Information Sciences and Systems (CISS'97)*, pp. 954-959, The Johns Hopkins University, Baltimore, MD, March 1997

167. M. Saquib, R. Yates, N.B. Mandayam "Decision Feedback Decorrelating Detector for a Dual Rate Synchronous DS/CDMA Channel," in *Proceedings of IEEE GLOBECOM'96*, vol. 3, pp. 1804-1808, London, U.K., November, 1996

168. N.B. Mandayam, P.C. Chen, J. Holtzman "Time Dependent Outages in Cellular Systems : Minimum Duration Outages," in *Proceedings of the 34th Annual Allerton Conference on Communication, Control, and Computing*, pp. 835-844, Allerton, IL, October, 1996

169. P.C. Chen, N.B. Mandayam, J. Holtzman "Minimum Duration Outages for Cellular Systems with Reception Diversity", in *Proceedings of IEEE ICUPC'96*, vol. 1, pp. 245-249, Cambridge, September, 1996

170. A. Sampath, N.B. Mandayam, J. Holtzman "Analysis of an Access Control Mechanism for Data Traffic in an Integrated Voice/Data CDMA System," in *Proceedings of IEEE VTC'96*, vol. 3, pp. 1448-1452, Atlanta, May, 1996

171. N.B. Mandayam, P.C. Chen, J. Holtzman "Minimum Duration Outages for Cellular Systems : A Level Crossing Analysis", in *Proceedings of IEEE VTC'96*, vol. 2, pp. 879-883, Atlanta, May, 1996

172. M. Saquib, R. Yates, N.B. Mandayam "Decorrelating Detectors for a Dual Rate Synchronous DS/CDMA System," in *Proceedings of IEEE VTC'96*, vol. 1, pp. 377-381, Atlanta, May, 1996

173. M. Andersin, N.B. Mandayam, R. Yates "Subspace based SIR Estimation for Cellular Systems," in *Proceedings of IEEE VTC'96*, vol. 2, pp. 1155-1159, Atlanta, May 1996

174. A. Sampath, N.B. Mandayam, J. Holtzman "A Simple Model for Admission of Short Message Data in an Integrated Voice/Data CDMA System," *Proceedings of INFORMS (Operations Research Society of America)*, Washington D.C., May, 1996

175. N.B. Mandayam, J. Holtzman "Analysis of a Simple Protocol for Short Message Data Service in an Integrated Voice/Data CDMA System," *Proceedings of MILCOM, 1995*, vol. 3, pp. 1160-1164, San Diego, November, 1995

176. N.B. Mandayam, S. Verdú "Analysis of an Approximate Decorrelating Detector for CDMA Systems," *Proceedings of the 33rd Annual Allerton Conference on Communication, Control, and Computing*, pp. 1043-1052, Allerton, IL, October, 1995

177. N.B. Mandayam "Adaptive Interference Suppression for DS-CDMA with Impulsive Noise" *Proceedings of IEEE International Symposium on Information Theory*, p. 26, Whistler, B.C., September 1995

178. N.B. Mandayam, J. Holtzman, S. Barberis "Erlang Capacity of an Integrated Voice/Data Wireless CDMA System with Variable Bit Rate Sources," *Proceedings of PIMRC 1995*, vol. 3, pp. 1078-1082, Toronto, September 1995

179. N.B. Mandayam "Adaptive Linear Detection for DS-CDMA Communications in Impulsive Channels", *Proceedings of IEEE International Conference on Vehicular Technology (VTC)*, pp. 699-703, Chicago, IL, June 1995

180. N.B. Mandayam, J. Holtzman, and S. Barberis "Performance and Capacity of an Integrated Voice/Data Wireless CDMA System with Variable Bit Rate Sources," *Proceedings of International Workshop on Mobile Multimedia Communications MoMuc-2, 1995*, Bristol, U.K., April 1995

181. N.B. Mandayam, B. Aazhang, " An Adaptive Multiuser Interference Rejection Algorithm for DS-CDMA Systems", *Proceedings of IEEE International Symposium on Information Theory*, p. 135, Trondheim, Norway, June 1994

182. N.B. Mandayam, B. Aazhang, " An Adaptive Single-User Detector for Optical Code Division Multiple Access Systems", in *Proceedings of the 28th Annual Conference on Information Sciences and Systems (CISS'94)*, pp. 485-490, Princeton University, Princeton, March 1994

183. N.B. Mandayam, B. Aazhang, "Generalized Sensitivity Analysis of Optical Code Division Multiple Access Systems", in *Proceedings of the 27th Annual Conference on Information Sciences and Systems (CISS'93)*, pp. 302-307, The Johns Hopkins University, Baltimore, MD, March 1993.

184. N.B. Mandayam, B. Aazhang, "Error Probabilities for Fiber-Optic Code Division Multiple Access System", in *Proceedings of the International Symposium on Information Theory*, p. 43, San Antonio, TX, Jan 1993.

185. N.B. Mandayam, B. Aazhang, "Importance Sampling Simulation of Single User and Multi User Optical Communication Systems", in *Proceedings of the 25th Annual Conference on Information Sciences and Systems (CISS'91)*, pp. 822-827, The Johns Hopkins University, Baltimore, MD, March 1991.

186. B. Chakravarty, N.B. Mandayam, S. Mukhopadhyay, A. Patra, G.P. Rao, "Real-Time Parameter Estimation via Block Pulse Functions", In *28th Annual Conference of the Society of Instrument and Control Engineers (SICE)*, Matsuyama, Japan, pp. 1095-1098, July 1989.

POSTDOCTORAL ADVISEES:

- Kenza Hamidouche, Ph.D. CentraleSupélec, Gif-sur-Yvette, France, 2016
- S. Rasoul Etesami, Ph.D. University of Illinois at Urbana-Champaign, 2015
- Gokul Sridharan, Ph.D. University of Toronto, 2015
- Siun-Chuon Mau, Ph.D. Princeton University, 2000
- Paschalis Ligdas, Ph.D. University of Maryland, 1997

PAST ADVISEES:

- Ph.D. Students :
  1. Mohammad Yousefvand, Ph.D. February 2021, Thesis: "User Centric and Network Centric Approaches for Resources and Emergency Alert Optimization in Wireless Networks" (currently at Qualcomm)
  2. Tejashri Kuber, Ph.D. November 2020, Thesis: "Learning and Prediction using Radio and Non-Radio Attributes in Wireless Systems" (currently at Rutgers)
  3. Neelakantan Nurani Krishnan, Ph.D. November 2019, Thesis: "Pushing the Envelope of Wi-Fi Networks Using Distributed Multi-user MIMO" (currently at Qualcomm)
  4. Mohammad Hajimirsadeghi, Ph.D. September 2018, Thesis: "Game Theoretic Approaches for Design of Information Centric Networks (ICN) and Spectrum Sharing" (currently at Princeton University)

5. Ahmed Alabdel A. Abass, Ph.D. May 2018, Thesis: "Evolutionary Games: Applications to Security and Resource Allocation" (currently at University of Thi-Qar, Iraq)
6. Ratnesh Kumbhkar, Ph.D. December 2017, Thesis: "Opportunistic Access of Noncontiguous Spectrum - Exploring use of Noncontiguous OFDM transmission for Dynamic Spectrum Access" (currently at Marvell Semiconductors)
7. Kai Su, Ph.D. May 2016, Thesis: "Algorithms and Protocols for Efficient Multicast, Transport, and Congestion Control in Wireless Networks" (currently at VMware) (Co-advisor: D. Raychaudhuri)
8. Wenjia Yuan, Ph.D. September 2014, Thesis: "Computational Photography Methods for Visual MIMO" (currently at Google) (Co-advisors: K. Dana and M. Gruteser)
9. Muhammad Nazmul Islam, Ph.D. September 2014, Thesis: "Noncontiguous Spectrum Access and Small Cell Network Design" (currently at Qualcomm)
10. Ashwin Ashok, Ph.D. June 2014, Thesis: "Design, Modeling and Analysis of Visual MIMO Communication" (currently at CMU) (Co-advisor: M. Gruteser, K. Dana)
11. Narayanan Krishnan, Ph.D. September 2013, Thesis: "Bandwidth Sharing and Massive MIMO for Next Generation Cellular Systems" (currently at Qualcomm) (Co-advisor: R. Yates)
12. Tianming Li, Ph.D. September 2013, Thesis: "Cognitive Radio Networks: Resource Allocation and Effect of End-User Behavior" (currently at J. P. Morgan)
13. Dan Zhang, Ph.D. September 2012, Thesis: "On the Dynamics of Random Network Coding" (currently at Qualcomm)
14. Suhas Mathur, Ph.D. July 2010, Thesis: "Building Information-Theoretic Confidentiality and Traffic Privacy into Wireless Networks" (currently at AT&T), (Co-advisors: W. Trappe and L. Greenstein)
15. Chandrasekharan Raman, Ph.D. February 2010, Thesis: "Relaying and Scheduling in Interference Limited Wireless Networks" (currently at Alcatel-Lucent), (Co-advisors: R. Yates and G. Foschini)
16. Liang Xiao, Ph.D. March 2009, Thesis: "PHY-Techniques to Improve Higher-Layer Functions in Wireless Networks" (currently Associate Professor at Xiamen University), (Co-advisors: W. Trappe and L. Greenstein)
17. Zhuyu Lei, Ph.D. December 2008, Thesis: "Utility-based Power Control for Packet-Switched Wireless Networks" (currently at Alcatel-Lucent, IL)
18. Hongbo Liu, Ph.D. November 2007, Thesis: "Cross-layer Design for Reliable and Efficient Data Transmission over Multiple Antenna Mobile Infostation Networks" (currently at Spirent, NJ)
19. Omer Ileri, Ph.D. June 2007, Thesis: "Dynamic Spectrum Access Models: Towards an Engineering Perspective in the Spectrum Debate" (currently at Royal Institute of Technology (KTH))
20. Lalitha Sankaranarayanan, Ph.D. May 2007, Thesis: "Relay Cooperation in Multiaccess Networks" (currently Assistant Professor at Arizona State University, was a post-doc at Princeton University)
21. Hitesh Nama, Ph.D. February 2007, Thesis: "Resource Allocation in Cooperative and Non-cooperative Energy-constrained Wireless Networks" (currently at Marvel Semiconductor)
22. Salim Manji, Ph.D. September 2004, Thesis: "Rate Adaptation Strategies for Progressive Image Transmission over Fading Channels" (currently at Spirent Technologies, NJ)
23. Nan Feng, Ph.D. July 2004, Thesis: "User Centric and Network Centric Radio Resource Management" (currently at Alcatel-Lucent Technologies, NJ)
24. Dragan Samardzija, Ph.D. April 2004, Thesis: "Multiple Antenna Wireless Systems and Channel State Information" (currently at Bell Labs, Alcatel-Lucent Technologies, NJ)

25. Heng Wang, Ph.D. December 2002, Thesis: "Opportunistic Transmission for Wireless Data over Fading Channels under Energy and Delay Constraints" (currently at Qualcomm)
26. Cristina Comaniciu, Ph.D., December 2001, Thesis: "Integrated Access Control and Detection for QoS in Multimedia CDMA Networks" (currently Associate Professor at Stevens Institute of Technology; was post-doc at Princeton University)
27. Jie Lai, Ph.D., August 2001, Thesis: "Performance of Channel Coding on Temporally and Spatially Correlated Wireless Channels" (currently at Broadcom Inc.)
28. Lei Song, Ph.D., August 2001, Thesis: "Resource Allocation Based on Hierarchical and Nonlinear Control in Wireless Networks" (currently at UTStar Telecom Inc.)
29. Cem Saraydar, Ph.D., December 2000, Thesis: "Pricing and Power Control in Wireless Data Networks" (currently at GM Research)

- M.S. Students :

1. Leonard Park, M. S. April 2016, Thesis: "Psychophysics Testbed and Experiments for Assessing End-User Perception of Video QoS over Wireless Channels"
2. Cyrus Gerami, M.S. May 2011, Thesis: "Spatio-Spectral Mapping of TV White Space in NJ"
3. Tejaswy Hari, M.S. October 2009, Thesis: "Implementation of an Adaptive MIMO-OFDM Cognitive Radio"
4. Suhas Mathur, M. S. October 2006, Thesis: "Coalitional Games in Cooperative Networks"
5. Omer Ileri, M. S. October 2003, Thesis: "Pricing for Enabling Forwarding in Wireless Adhoc Networks"
6. Shrenik Patel, M.S., December 2002, Thesis: "Comparative Evaluation of OFDM and Single-Carrier Equalization Schemes for Infostation Channels" (currently at Time Domain Inc.)
7. Andrej Domazetovic, M.S., September 2002, Thesis: "Propagation Models for Short-Range Wireless Channels with Predictable Path Geometries" (currently at Ibiquity Digital)
8. Shaily Verma, M.S., July 2001, Thesis: "QoS Provisioning for Mobile Internet Access via GPRS/EDGE" (currently at Thomson Electronics)
9. Dragan Samardzija, M.S., June 2000, Thesis: "Blind Interference Cancellation Schemes for DS-CDMA Systems" (currently at Lucent Technologies)
10. Nan Feng, M.S., June 1999, Thesis: "Joint Power and Rate Optimization for Utility Maximization in Wireless Data Networks", (currently pursuing Ph.D. at Rutgers)
11. Kamesh Medapalli, M.S., December 1998, Thesis: "TDMA Interference Cancellation and Equalization using Tentative Decisions" (currently at Stanford University)
12. Viral Shah, M.S., March 1998, Thesis: "Power Control for Wireless Data Services based on Utility and Pricing" (currently at Qualcomm, Inc.)
13. Deepa Ramakrishna, M.S., June 1997, Thesis: "Subspace Based Estimation of the Signal to Interference Ratio for CDMA Cellular Systems"

CURRENT ADVISEES:

- Ph.D. & M.S. Students :

1. Sijie Xiong, Ph.D. Thesis: Privacy and Resource Allocation in IoT (co-advisor with A. Sarwate)
2. Mohsen Rajabpour, Ph.D. Thesis: Privacy and End-User Behavior with Applications to IoT and Smart Grid (co-advisor with A. Sarwate)

3. Alireza Nooraiepour, Ph.D. Thesis: Learning-Aided Physical Layer Security for IoT (co-advisor with W. Bajwa)
4. Nitya Sathyavageeswaran, Ph.D. Thesis: Privacy and Age of Information (co-advisor with A. Sarwate and R. Yates)
5. Zahra Aref, Ph.D. Thesis: Advanced Persistent Threats and End-User Behavior
6. Demetrios Lambropoulos, Ph.D. Thesis: Impact of End-User Behavior and Non Radio Attributes on Resource Allocation

UNDERGRADUATE RESEARCH INITIATIVES:

1. "Eagle Eye Multi UAV Reconnaissance," Spring 2020. In this project, students designed and protyped a multi UAV reconnisance system for search and recue operations when communications infrastructre is compromised. (Students: Kaavya Krishna-Kumar, Sagar Shah, Harmit Badyal, Abhishek Kondila)
2. "Tracking Rutgers Students for Traffic Optimization," Spring 2015. In this project, students are designing a module that will use the Cisco CMX API to gather data, process it into useful metrics, and present it in a fashionable form to optimize transportation traffic across the Rutgers campuses. (Students: Jason Scatena, Dan Su, Samin Rahman, Peter Zhang)
3. "Resonance based Wireless Power Transfer." Fall 2013. In this project, students designed a prototype device for remotely charging cell phones. (Students: Hiren Patel, Parth Patel, Nikunj Shah)
4. "Spectrum Sensing using GNU Radios" Fall 2006 and Spring 2007. In this project we use the GNU software defined radio toolkit to design a spectrum sensor which can sniff the spectrum of interest and identify transmitting devices (Student: Janani Kalyanam)
5. "Electrical Engineering Building WiFi Measurements & Analysis", Spring 2007. A group of 6 undergraduate students conducting measurements, modeling and prediction of WiFi signal coverage in the EE building on Busch Campus at Rutgers University (Students: Rodney Gataeu, Daniel Austin, Francois M. Jean-Noel, Nandita Mitra, Shil Madiwala, Michael Kasmer)
6. "Wireless Networking Effects in Multistory Buildings using NetStumbler", Spring 2007. A group of 7 undergraduate students conducting measurements, modeling and prediction of WiFi signal coverage in the coRe building on Busch Campus at Rutgers University (Students: Sunny Balwani, Tanya Busayadilok, Niharika Gajawelli, Janani Kalyanam, Rohan Panjwani, Priti Shah, Jerry Yick)
7. "Busch Campus Center WiFi Measurements & Analysis" Spring 2006. A group of 4 undergraduate students conducting measurements, modeling and prediction of WiFi signal covergae in the Busch Campus Center at Rutgers University (Students: Suhrid Bhatt, Smeet Modi, Jigar Pathak, Lakshmi Murthy)
8. "Implementation of a Blind Successive Interference Canceller for CDMA" Spring 2002. A group of 3 undergraduate students built an SPW system emulation for blindly cancelling CDMA encoded interference from CDMA encoded voice transmissions (Students : Ahmad Turk, John Youssuf, Pranav Amin)
9. "Simulations of Coding Spreading Tradeoffs in CDMA Systems" Fall 1999 and Spring 2000. One undergraduate student (Siamak Sorooshyari) worked on SPW simulations for understanding partitioning of bandwidth expansion in CDMA systems between channel coding and bandwidth spreading.
10. "Analysis and Design of an Infostation Testbed" (with Dr. I. Marsic): Fall 1999. A group of 7 undergraduate students building an infostation testbed including GUI and a rotating directional antenna to emulate drive-through and walk-through environments in an infostation setting (Students : Milton Cobo, Paul DiBenedetto, Phil Futernik, Michael Girone, Ulysses Gonzalez, Louis Lagonik, Nitish Sinha)

11. "Using Ad-Hoc Networks in Crisis Management" (with Dr. D. Goodman and Dr. I. Marsic): Spring 1999. A group of 15 undergraduate students built a demo including GUI and network support that facilitates multimodal collaboration across wired and wireless links in case of FIRE emergencies. (Students :S. Ali, E. Chen, O. Lewis, D. Mulato, M. Patel, A. Ogunshola, L. Rivera, A. Rowan, R. Sekhar, M. Shah, N. Shakir, D. Tabora, J. Tunis, K. Vapiwala, J. Vora)
12. "WCT: Wireless Collaborative Teleconferencing" (with Dr. D. Goodman): Fall 1998. A group of 13 undergraduate students worked on the creation of a concept that facilitates multimodal collaboration across wired and wireless links in case of FIRE emergencies. (Students :S. Ali, S. Chowdhury, C. Larson, G. Mittal, A. Ogunshola, T. Osinubi, L. Rivera, A. Rowan, R. Sekhar, N. Shakir, D. Tabora, J. Tunis, T. Zacharia)
13. "WISP-II: Wireless Internet Special Problems - Part II" (with Dr. D. Goodman): Spring 1998. A group of 10 undergraduate students worked on a prototype of the device "NaviDator" that provided location based mobile services including emergency and yellow page information. (Students: M. Anguin, A. Haidri, T. Holman, J. Ken-Kwofie, D. Ngo, A. Srivastava, R. Sharma, A. Tiwari, M. Vachharajani, A. Whittaker)
14. "WISP: Wireless Internet Special Problems" (with Dr. D. Goodman): Fall 1997. A group of 15 undergraduate students worked on the creation of a concept device called "NaviDator" that provided location based mobile services including emergency and yellow page information. (Students : M. Anguin, P. Boutros, M. Canuel, S. Ercilasun, A. Haidri, K. Harris, S. Ke, J. Ken-Kwofie, D. Ngo, A. Srivastava, R. Sharma, S. Tamhankar, A. Tiwari, M. Vachharajani, A. Whittaker)
15. "Bayesian Decision making in an AlterEgo server" : Spring 1997. Testing decision rules for message forwarding to mobile hosts in Email management servers (Student: Stephan Samuel)

UNDERGRADUATE CO-OP PROGRAM ADVISING:

1. Christopher Shin, Verizon Wireless (Jun-Dec 2001)
2. Swarna Gadiraju, Motorola (Aug-Dec 2001)

NEW COURSES

1. "Wireless Revolution" (14:332:301) (introduced in Fall 2008) This multidisciplinary course is intended for all undergraduate students (from engineering, science, arts, business, economics, and humanities) who have an interest in the strategic problems that emerge when companies and entrepreneurs set out to create successful new businesses. A primary objective of the course is to demonstrate (using wireless communications systems as an illustrative example) that students from all disciplines can understand a wide range of strategic issues at a basic, intuitive level, and can use this basic understanding to solve important real-world problems. Has been offered in Flip'd mode in 2020 and 2021.
2. "Wireless Instructional System Design" (introduced in Spring 2004): This instructional "hands-on" design course covers PHY, MAC, Networking and Application layers of wireless systems
3. "Wireless Communications Technologies" (introduced in Spring 1999): This course has since been adopted permanently into the graduate curriculum of the Department of Electrical & Computer Engineering, Rutgers University (Course No. 16:332:546)
4. "INFOSTATIONS- Challenges in the Creation of a New Wireless System" (Fall 1996). A multidisciplinary course involving graduate students from Electrical & Computer Engineering (ECE), Computer Science (CS), and School of Information and Library Studies (SCILS).

TEACHING

1. "Introduction to Computers for Engineers" - Fall 2015
2. "Wireless Revolution" - Spring 2021, 2020, 2019, 2018, 2017; Fall 2014, 2013, 2011,2010,2009,2008

3. ”Wireless Personal Communications Systems” - Spring 2007
4. “Probability and Random Processes” - Fall 2001,2000,1999
5. “Wireless System Design” - Spring 2004,2005
6. “Wireless Communication Technologies” - Spring 2015, 2013, 2011, 2009,2005, 2004,2002,2001,2000,1999
7. “Communications Engineering” - Fall 2007,2004,1998,1997
8. “Detection and Estimation Theory” - Spring 2014, 2012,2010,2008,2006,2003,1998,1997
9. “INFOSTATIONS- Challenges in the Creation of a New Wireless System” - Fall 1996

DEPARTMENT/SCHOOL/UNIVERSITY SERVICE AND ACTIVITIES:

1. University Network Infrastructure Steering Committee, 2020-21
2. School of Engineering, Distinguished Professor Promotion Committee, 2015-16
3. ECE Department Strategic Planning Committee, Rutgers University, 2006-present
4. ECE Undergraduate Curriculum Revision Committee, 2012-present
5. Member, Committee on Corporate Partnerships, Office of VP of Research and Economic Development, 2011-12
6. Chair, ECE Chair Search Committee, Rutgers University 2009-10
7. ECE Faculty Search Committee, Rutgers University 2006-2012
8. School of Engineering Academic Promotion and Tenure Committee, Rutgers University - 2007-2008, 2008-2009
9. Faculty Advisor, IEEE Student Branch, Rutgers University, Jan. 1997-December 2002
10. Engineering Orientation Lecture, Rutgers University - November 1996, November 1997, November 1998, December 2001, February 2002, Spring 2009, Fall 2012, Spring 2013,
11. Engineering Open House (led one ECE Department “Info-session” almost every year for the last several years)
12. Undergraduate and Graduate Student Advising
13. Graduate Committees: Scholastic Standing Committee, Graduate Admissions Committee
14. Undergraduate Committees: Scholastic Standing Committee
15. Marshall at School of Engineering Commencement Ceremonies, Rutgers University - 1996-1999, 2010,2011,2012

SOCIETY/TECHNICAL ACTIVITIES:

1. Distinguished Lecturer of the IEEE Communications Society (COMSOC), 2012-15
2. Technical Program Co-Chair, IEEE WiOPT 2011, Princeton NJ
3. Member, IEEE Technical Committee on Green Multimedia Communications (since 2010)
4. Guest Editor, IEEE JSAC Special Issue on Game Theory in Communications and Networking (September 2008)
5. Guest Editor, IEEE JSAC Special Issue on Spectrum Agile Cognitive Radio Networks (April 2007)
6. Editor, IEEE Transactions on Wireless Communications, 2002-2005
7. Associate Editor, IEEE Communications Letters, 1999-2002
8. IEEE Student Branch Counsellor, Rutgers University, Jan. 1997-Dec. 2002
9. Member of Technical Program Committees of several IEEE conferences over the last several years (e.g. ICC, Globecom, DySpaN, CrownComm, WiOPT)

10. Panel Leader and Organizer for *"Communicating in TV White Space"* at IEEE Communication Theory Workshop (CTW'2010), Cancun, Mexico, May 2010
11. Panelist for *"Towards Green Wireless"* at IEEE Saranoff Symposium, Princeton, NJ, April 2010
12. Session Chairman, "Adhoc/Multihop Networks" IEEE International Symposium on Wireless Communications, ISWC'02, Victoria, Bristish Columbia, Canada, September 2002
13. Session Chairman, "MAC Performance" IEEE Vehicular Technology Conference, VTC'02 Fall, Vancouver, Canada, September 2002
14. Session Chairman, "CDMA", Conference on Information Sciences and Systems, CISS'02, Princeton University, March 2002
15. Session Organizer and Chairman, "Multirate Spread Spectrum Techniques and Systems", IEEE International Symposium on Spread Spectrum Techniques and Applications, ISSTA'2000, Parsippany NJ, September 2000
16. Session Organizer and Chairman, "CDMA Performance Enhancements", IEEE International Conference on Communications, ICC'98, Atlanta, GA, June 1998
17. Session Chairman, "Wireless Communications Systems" Conference on Information Sciences and Systems, CISS'99, The Johns Hopkins University, Baltimore, MD, March 1999.
18. Reviewer for IEEE Journals (Transactions on Communications, Transactions on Wireless Communications, Information Theory, Signal Processing, Vehicular Technology, Automatic Control and Selected Areas in Communications)
19. Panelist and Reviewer for National Science Foundation (NSF)