EXHIBIT A

Exhibit A - U.S. Patent No. 8,891,347 ("'347 Patent")

Accused Instrumentalities: (1) cellular base stations that support 3GPP 5G NR beamforming, and (2) cellular user equipment (UE) that supports 3GPP 5G NR beamforming.

Based upon publicly available information and without the benefit of discovery in this case, the accused base stations include, but are not limited to the following products sold by Nokia, Ericsson, and Samsung:

Nokia: AirScale base station, AirScale radio and baseband, AirScale 5G mMIMO base station, ReefShark System on Chip and all products containing the same, AirScale Osprey, AirScale Habrok, AirScale mRRH, AirScale pRRH, AirScale 4.5G Pro RRH, AirScale sHUB, FZHR, AHBOA, FSIH, FHFB, AZHL, AAFIA, 32TRX, and 64TRX.

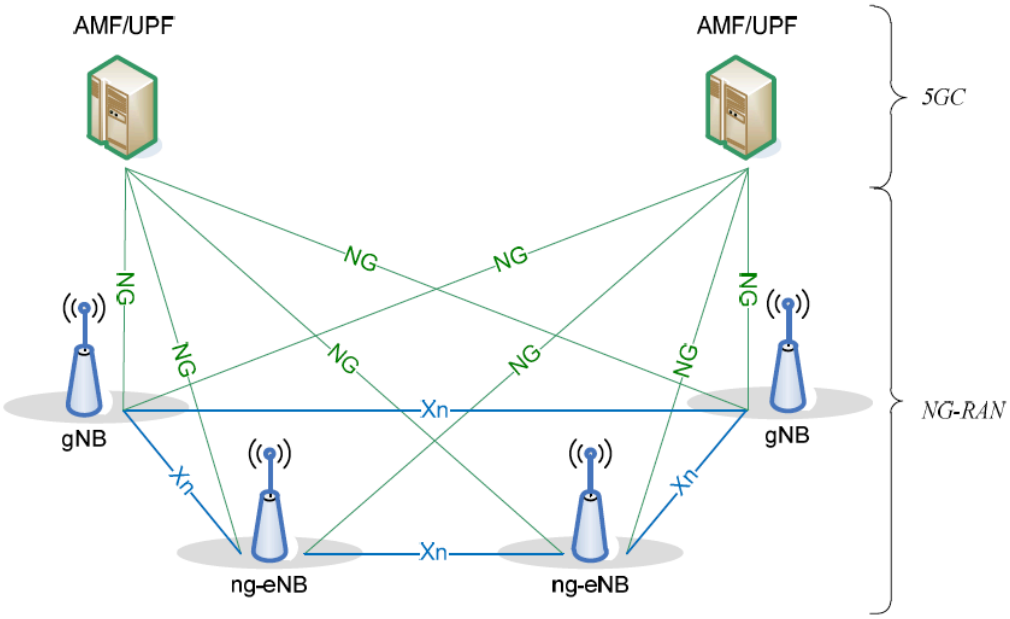
Ericsson: 5G AIR products, 5G Baseband products, 5G Radio products, 5G Antenna products, AIR 1279, AIR 3218, AIR 3219, AIR 3229, AIR 3239, AIR 3246, AIR 3258, AIR 3268, AIR 3283, AIR 6419, AIR 6428, AIR 6468, AIR 6476, AIR 6488, Interleaved AIR, Baseband 5216, Baseband 6502, Baseband 6648, 5G Radio Dot, Radio 4407, Radio 4408, Radio 4412, Radio 4418, Radio 4485, Radio 4490, Radio 8808, Radio 8863, Antenna 4600, Antenna 4602, Antenna 5500, and Antenna 6600.

Samsung: 5G base stations, 4T4R CBRS Radio, 32T32R Radio, 64T64R Radio, C-Band Radio, CDU50, One Antenna Radio, Link Hub, and Link HubPro.

The accused UE devices include without limitation the Apple iPhone 12, iPhone 12 mini, iPhone 13, iPhone 13 mini, iPhone 13 Pro, iPhone 13 Pro Max, iPhone 14, iPhone 14 Plus, iPhone 14 Pro, iPhone 14 Pro Max, iPhone SE, iPad, iPad Air, iPad Mini, iPad Pro 11-inch, and iPad Pro 12.9-inch; Samsung Galaxy S10, Galaxy S20, Galaxy S20+, Galaxy S20 Ultra, Galaxy S20 FE, Galaxy S21, Galaxy S21+, Galaxy S21 Ultra, Galaxy S21 FE, Galaxy S22, Galaxy S22+, Galaxy S22 Ultra, Galaxy S23, Galaxy S23+, Galaxy S23 Ultra, Galaxy Z Flip3, Galaxy Z Flip4, Galaxy Fold, Galaxy Z Fold2, Galaxy Z Fold3, Galaxy Z Fold4, Galaxy A13, Galaxy A14, Galaxy A22, Galaxy A23, Galaxy A32, Galaxy A33, Galaxy A42, Galaxy A51, Galaxy A52, Galaxy A53, Galaxy A71, Galaxy A73, Galaxy A90, Galaxy F42, Galaxy F52, Galaxy M13, Galaxy M32, Galaxy M42, Galaxy M52, Galaxy Note 10, Galaxy Note 10+, Galaxy Note 20, Galaxy Note 20 Ultra, and Galaxy Quantum 2; Google Pixel 4a, Pixel 5, Pixel 5a, Pixel 6, Pixel 6a, and Pixel 7; Motorola Edge, Edge+, G Play, G Power, G Pure, G Stylus, and One; and UE devices (such as Wi-Fi gateway devices) provided for use with defendant's home 5G Internet services.

Claim 1

Claim 1	Public Documentation
[1pre] A method for wireless communication in a system including a transmitter, a receiver, and a plurality of propagation paths formed between the transmitter and the receiver which are capable of carrying a signal transmitted by the transmitter to the receiver, the method comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities perform a method for wireless communication in a system including a transmitter, a receiver, and a plurality of propagation paths formed between the transmitter and the receiver which are capable of carrying a signal transmitted by the transmitter to the receiver. For example, the Accused Instrumentalities perform a method for beamforming 5G NR transmissions between a base station and user equipment (UE) utilizing the multipath transmission environment between the transmitter and receiver. This method is described, for example, in 3GPP standards documents such as TR 38.901 V15.0.0, TS 38.300 V2.0.0, and associated documents, which describe aspects of the operations associated with components of the Accused Instrumentalities. **4.1 Overall Architecture** An NG-RAN node is either: - a gNB, providing NR user plane and control plane protocol terminations towards the UE; or - an ng-eNB, providing E-UTRA user plane and control plane protocol terminations towards the UE. The gNBs and ng-eNBs are interconnected with each other by means of the Xn interface. The gNBs and ng-eNBs are also connected by means of the NG interfaces to the 5GC, more specifically to the AMF (Access and Mobility Management Function) by means of the NG-C interface and to the UPF (User Plane Function) by means of the NG-U interface (see TS 23.501 [3]). NOTE: The architecture and the F1 interface for a functional split are defined in TS 38.401 [4].

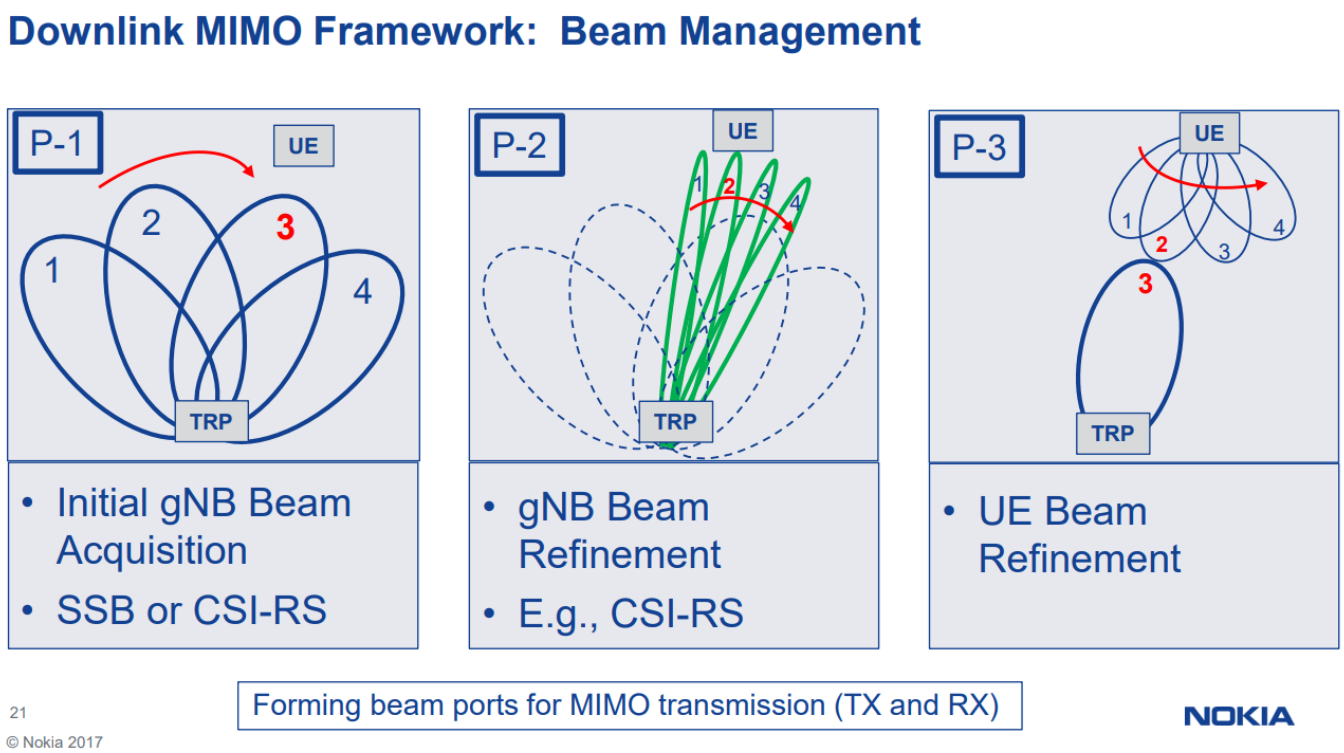
Claim 1	Public Documentation
	The NG-RAN architecture is illustrated in Figure 4.1-1 below.  **Figure 4.1-1: Overall Architecture** (3GPP TS 38.300 v17.2.0, § 4.1) LCS Local Coordinate System LOS Line Of Sight MIMO Multiple-Input-Multiple-Output MPC Multipath Component NLOS Non-LOS (3GPP TR 38.901 v15.0.0, § 3.2)

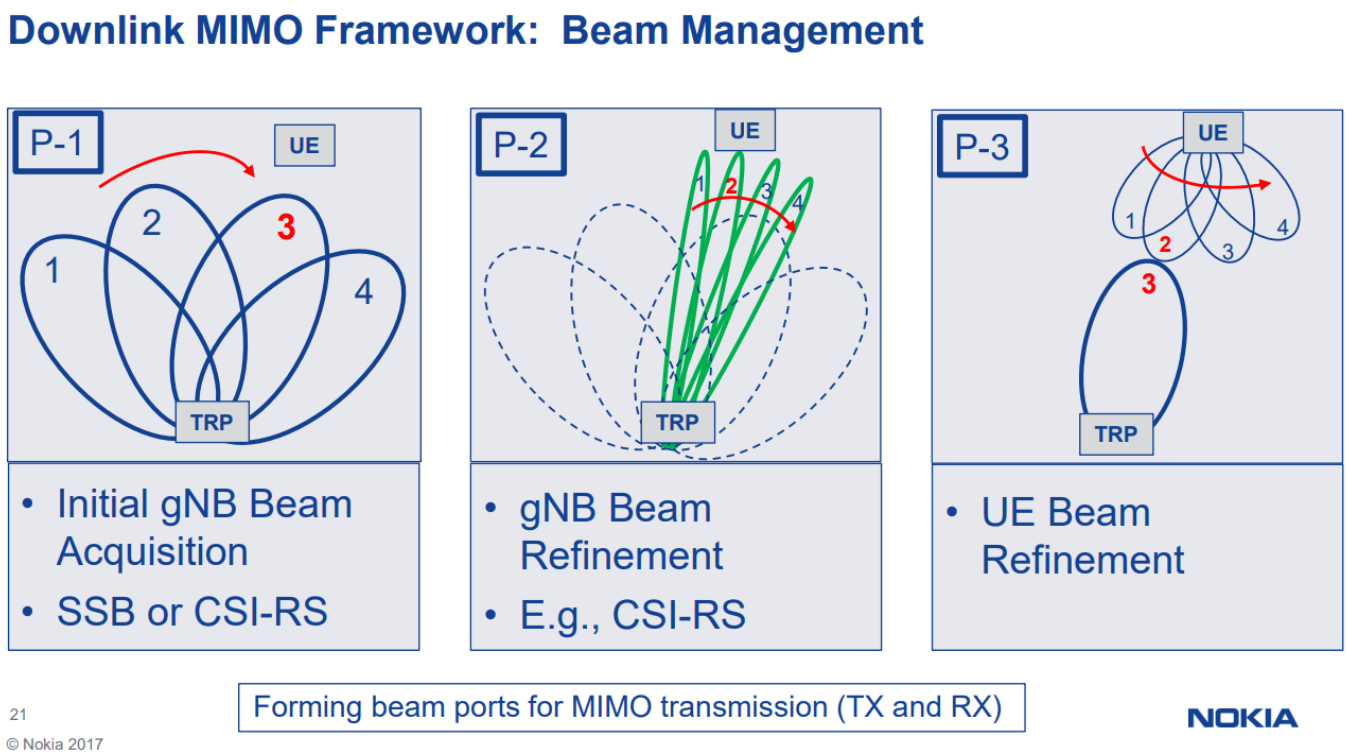
Claim 1	Public Documentation
	4. The number of rays per cluster shall be calculated as follows: $$M = \min\{\max(M_t M_{\mathrm{AOD}} M_{\mathrm{ZOD}}, 20), M_{\max}\} \quad (7.6\text{-}8)$$ where: - $M_t = \lceil 4kc_{\mathrm{DS}}B \rceil$ - $M_{\mathrm{AOD}} = \left\lceil 4kc_{\mathrm{ASD}} \frac{\pi \cdot D_h}{180 \cdot \lambda} \right\rceil$ - $M_{\mathrm{ZOD}} = \left\lceil 4kc_{\mathrm{ZSD}} \frac{\pi \cdot D_v}{180 \cdot \lambda} \right\rceil$ - $M_{\max}$ is the upper limit of M, and it should be selected by the user of channel model based on the trade-off between simulation complexity and accuracy. - D_h and D_v are the array size in m in horizontal and vertical dimension, B is bandwidth in Hz, c_{ASD} and c_{ZSD} are the cluster spreads in degrees, and λ is the wavelength. - k is a "sparseness" parameter with value 0.5. It is noted that each MPC may have different AOD, ZOD, and delay. (3GPP TR 38.901 v15.0.0, § 7.6.2.2)

Claim 1	Public Documentation
	Table 7.8-4: Simulation assumptions for calibration for large bandwidth and large antenna array

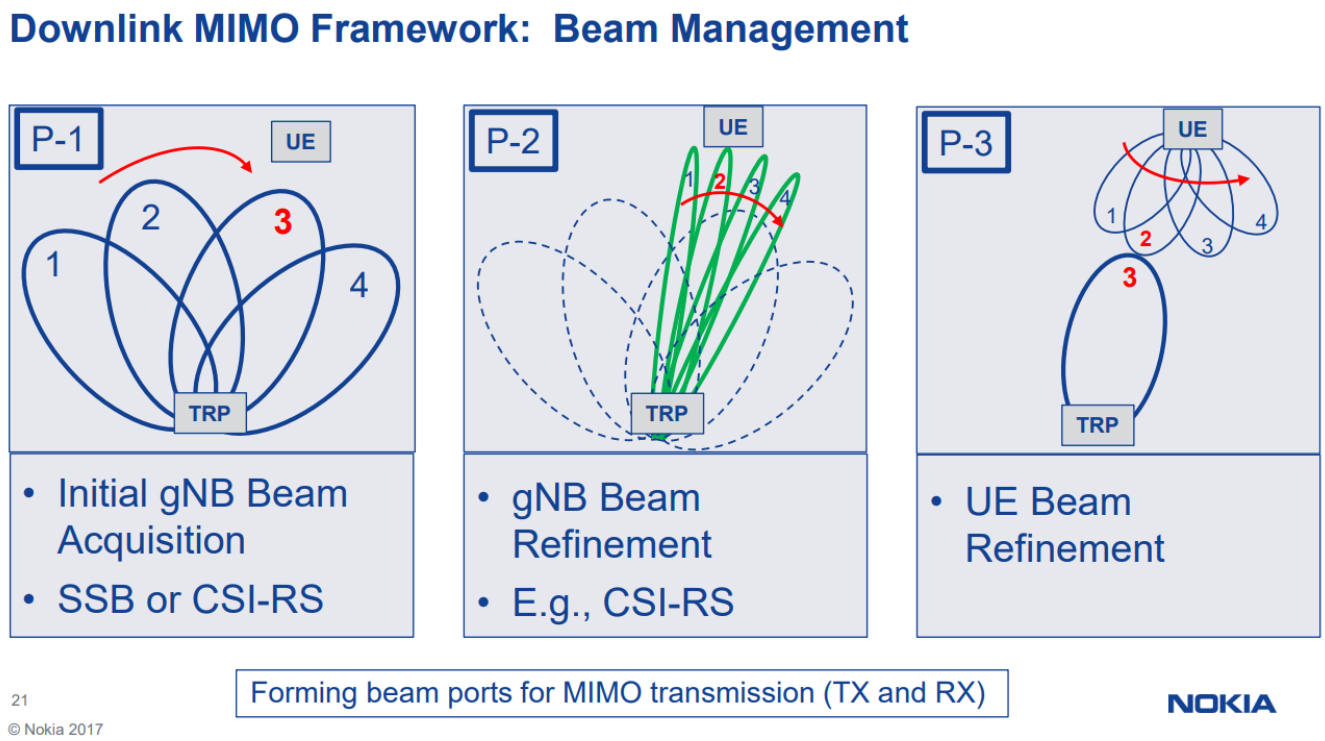
Parameter	Values
Scenarios	UMi-street Canyon
Carrier Frequency	30GHz
Bandwidth	2GHz
BS antenna configurations	$M = 8$, $N = 8$, $P = 2$, $M_g = 1$, $N_g = 4$, $d_H = d_V = 0.5\lambda$, $d_{H,g} = d_{V,g} = 4\lambda$
BS port mapping	all 64 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations
The number of rays per cluster	$N_{MPC} = 40$
Calibration method	Drop multiple users in the multiple cells randomly, and collect the following metrics for each user after attachment.
Metrics	1) CDF of coupling loss (serving cell) 2) Wideband SINR before receiver – determined from RSRP (formula) from CRS port 0 3) CDF of largest (1st) PRB singular values (serving cell) at t=0 plotted in 10*log10 scale

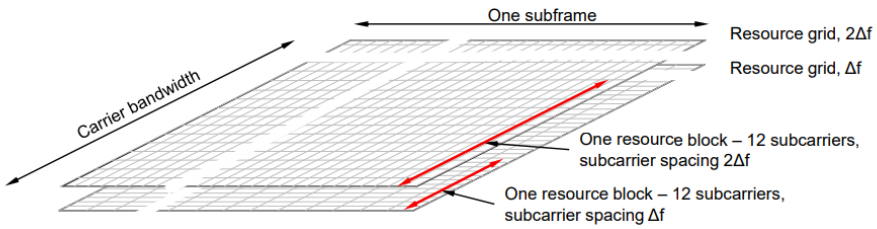
(3GPP TR 38.901 v15.0.0, Table 7.8-4)

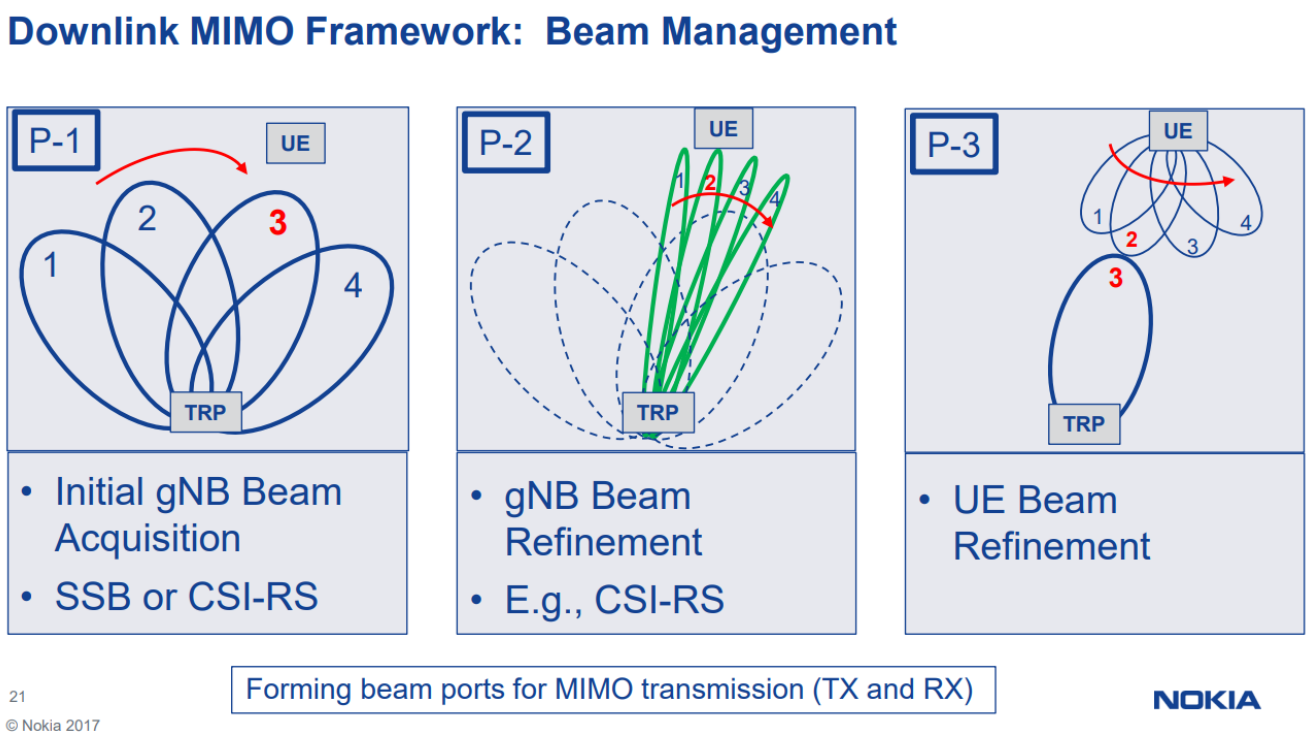
Claim 1	Public Documentation
[1a] transmitting a first signal from the transmitter to the receiver via a first propagation path of the plurality of propagation paths;	The Accused Instrumentalities perform a method including transmitting a first signal from the transmitter to the receiver via a first propagation path of the plurality of propagation paths. For example, the base station initially transmits via a narrow-beam antenna to the UE. This is illustrated in the diagrams below as, for example and without limitation, the initial gNB beam (which is one of the plurality of propagation paths).  (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)
[1b] receiving the first signal at the receiver;	The Accused Instrumentalities perform a method including receiving the first signal at the receiver. For example, the UE receives the initial transmission as described above and below.

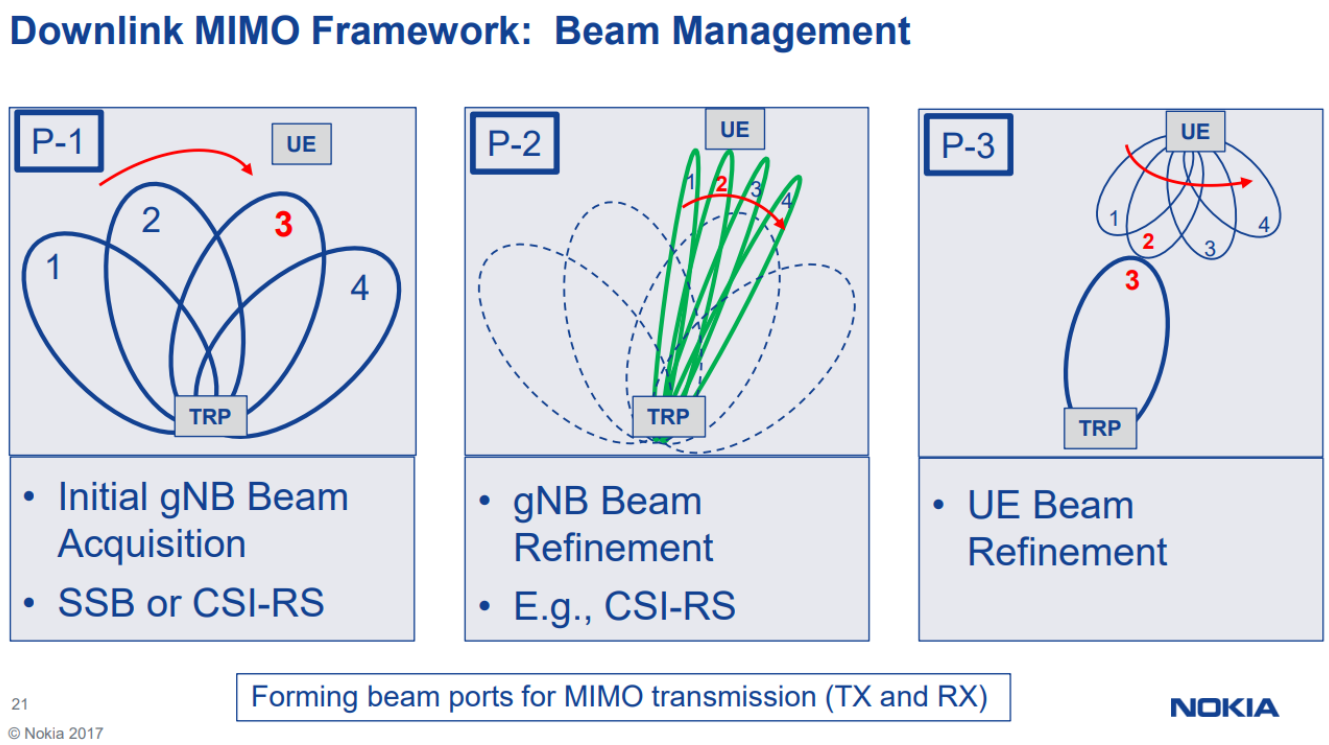
Claim 1	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)
[1c] performing a channel estimation based on the first signal to obtain path parameter information of the first propagation path;	The Accused Instrumentalities perform a method including performing a channel estimation based on the first signal to obtain path parameter information of the first propagation path. For example, the UE performs link channel state estimation based on the first signal, which includes information that is required by the gNB.

Claim 1	Public Documentation
	5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1)
[1d] sending the channel estimation that includes the path parameter information from the receiver to the transmitter via the first propagation path;	The Accused Instrumentalities perform a method including sending the channel estimation that includes the path parameter information from the receiver to the transmitter via the first propagation path. For example, the UE sends the estimated channel state back to the gNB. In at least TDD mode (as used by 5G NR FR2 with beamforming), the uplink transmission uses the same propagation path (via reciprocity) as the downlink transmission. 5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1)

[1e] predistorting a second signal at the transmitter in a time domain, a frequency domain, and a spatial domain, according to the channel estimation based on the first signal;	The Accused Instrumentalities perform a method including predistorting a second signal at the transmitter in a time domain, a frequency domain, and a spatial domain, according to the channel estimation based on the first signal. For example, a 5G NR signal with beamforming is a predistorted signal in time, frequency, and space. For example, applicable time and frequency subcarriers are selected based on the returned CSI, and an appropriate spatial beam refinement is selected based on the returned CSI.  (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)

Claim 1	Public Documentation
	Resource grid - One resource grid per numerology and antenna port - Resource block = 12 subcarriers - One dimensional unit (unlike LTE) - Resource element = 1 subcarrier in one OFDM symbol  (NR Physical Layer Design: Physical layer structure, numerology and frame structure Workshop on 3GPP submission towards IMT-2020, Brussels, Oct. 24-25, 2018, Havish Koorapaty 3GPP TSG RAN WG1 vice-chairman (Ericsson), available at https://www.3g4g.co.uk/5G/5Gtech_4001_3GPP_5GNR_IMT2020_EvaluationWorkshop_Oct2018/RWS-180007_3GPP%20NR%20Physical%20Layer%20Structure%20IMT2020.pdf). In this illustration, a resource block is placed in a particular subframe (by time) and resource block (by frequency, i.e. subcarriers).

Claim 1	Public Documentation
[1f] transmitting the predistorted second signal from the transmitter to the receiver via the first propagation path; and	The Accused Instrumentalities perform a method including transmitting the predistorted second signal from the transmitter to the receiver via the first propagation path. For example, the gNB transmits the beamformed signal as described in the previous element.  (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)

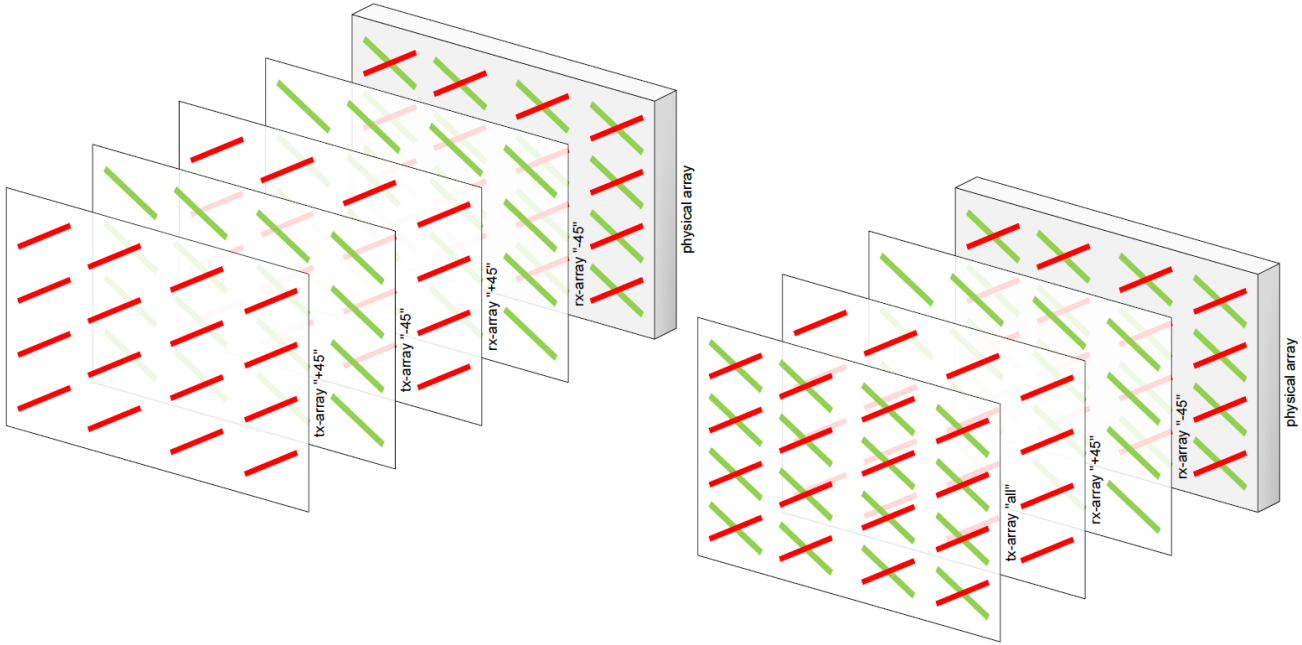
Claim 1	Public Documentation
[1g] receiving the predistorted second signal at the receiver.	The Accused Instrumentalities perform a method including receiving the predistorted second signal at the receiver. For example, the UE receives the beamformed signal as described in the previous two elements.  (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)

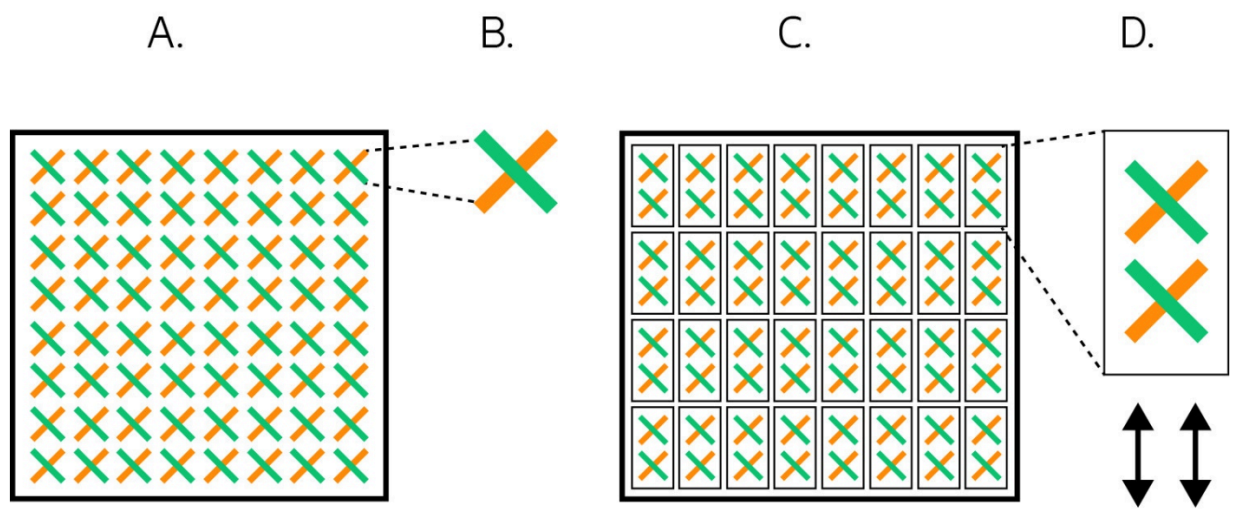
Claim 2

Claim 2	Public Documentation
[2] The method of claim 1, wherein the path parameter information of the first propagation path includes at least one of an estimation of a delay, an estimation of a Doppler frequency, an estimation of a direction of arrival, an estimation of a direction of departure, and an estimation of a complex amplitude of the first propagation path.	The Accused Instrumentalities perform a method wherein the path parameter information of the first propagation path includes at least one of an estimation of a delay, an estimation of a Doppler frequency, an estimation of a direction of arrival, an estimation of a direction of departure, and an estimation of a complex amplitude of the first propagation path. For example, in the Accused Instrumentalities the path parameter information of the first propagation path includes an estimation of a complex amplitude of the first propagation path. For example, the UE receives reference signals, such as CSI-RS reference symbols, and uses the signal to estimate the channel, and reports the channel state information back to the gNB. The propagation path impacts the phase and gain of the signal on each frequency tone which is measured by the UE; the phase and gain may be expressed as a complex number representing the complex amplitude. A 3GPP compliant UE must be able to receive reference signals, such as CSI-RS reference symbols, estimate the channel in the form of a complex amplitude on the OFDM tones, compute and report the estimated channel state to the gNB. 5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1) **Channel State Information Reference Signal (CSI-RS)** As a DL-only signal, the CSI-RS the UE receives is used to estimate the channel and report channel quality information back to the gNB. During MIMO operations, NR uses different antenna approaches based on the carrier frequency. At lower frequencies, the system uses a modest number of active antennas for MU-MIMO and adds FDD operations. In this case, the UE needs the CSI-RS to calculate the CSI and report it back in the UL direction. https://www.techplayon.com/5g-nr-reference-signals-dmrs-ptrssrs-and-csi-rs

Claim 3

Claim 3	Public Documentation
[3] The method of claim 2, wherein the path parameter information of the first propagation path further includes an estimation of a polarization status of the first propagation path.	The Accused Instrumentalities perform a method wherein the path parameter information of the first propagation path further includes an estimation of a polarization status of the first propagation path. For example, for the channel estimation of the propagation path, the base station transmits reference signals, such as CSI-RS reference signals, from both antenna polarizations. The UE measures the channel state information for signals received from each antenna polarization and reports the channel state information to the base station, to be used for beamforming via distorting the signal at the base station transmitter. The channel state information estimate for the propagation path for each antenna polarization is used for beamforming in 3GPP base stations that utilize dual-polarized antennas. The Accused Instrumentalities 3GPP base station antennas comprise multiple dual-polarized antenna elements:

Claim 3	Public Documentation
	10.5.5 Model Usage The O-RU antenna model reported by the O-RU consists of RX arrays and TX arrays. RX arrays and TX arrays represent a capability for transmitting/receiving RF signal related to an eAxC and - if beamforming is supported by O-RU on given array - beamforming capability. In this section examples are presented: red and green bars represent array elements of different polarizations, grey box represents physical device, white rectangles represent arrays reported by O-RU.  **Figure 10-7 : Examples of Model Usage – TX as two single-polarization arrays or one cross-polarized array** (O-RAN.WG4.CUS.0-v05.00, Technical Specification, O-RAN Fronthaul Working Group, Control, User and Synchronization Plane Specification)

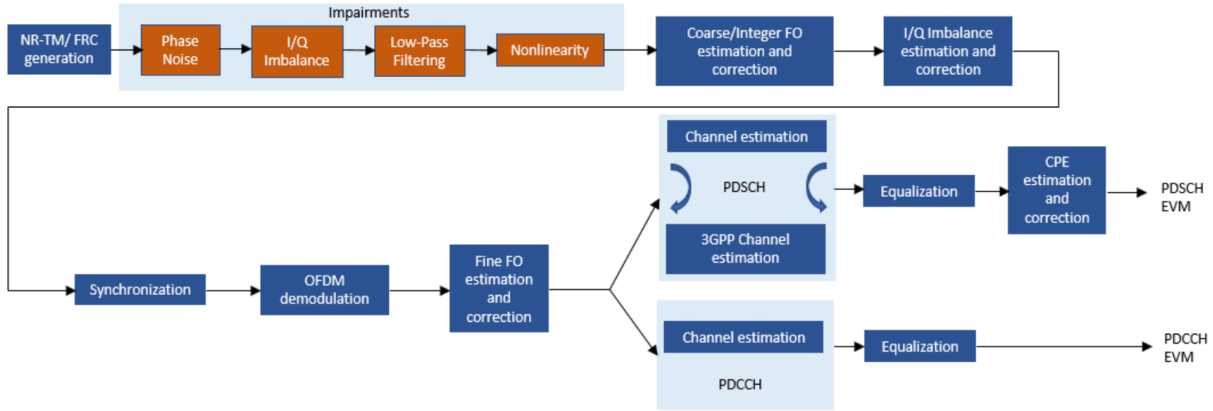
Claim 3	Public Documentation
	Antenna array structure The purpose of using a rectangular antenna array, as shown in section A of Figure 2, is to enable high-gain beams and make it possible to steer those beams over a range of angles. The gain is achieved, in both UL and DL, by constructively combining signals from a number of antenna elements. The more antenna elements there are, the higher the gain. Steerability is achieved by individually controlling the amplitude and phase of smaller parts of the antenna array. This is usually done by dividing the antenna array into so called sub-arrays (groups of non-overlapping elements), as shown in section C of Figure 2, and by applying two dedicated radio chains per sub-array (one per polarization) to enable control, as shown in section D. In this way it is possible to control the direction and other properties of the created antenna array beam.  Figure 2: A typical antenna array (A) is made up of rows and columns of individual dual-polarized antenna elements (B). Antenna arrays can be divided into sub-arrays (C), with each sub-array (D) connected to two radio chains, normally one per polarization. (https://www.ericsson.com/en/reports-and-papers/white-papers/advanced-antenna-systems-for-5g-networks)

Claim 4

Claim 4	Public Documentation

[4] The method of claim 1, wherein the path parameter information is obtained by at least one estimation technique of the group consisting of a maximum-likelihood estimation algorithm, periodogram, correlatorgram, spectral-based methods, Bartlett beamformers, Capon beamformers, subspace-based techniques, MUSIC (MUltiple SIgnal Classification), ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques), approximation of the maximum-likelihood method based on iterative schemes, SAGE (Space-Alternating Generalized Expectation-maximization), RiMAX (Richter's Maximum Likelihood method), maximum-a-posteriori based methods, Evidence Framework, Bayesian techniques, tracking algorithms, Kalman filtering techniques, enhanced Kalman filtering techniques, particle filtering techniques, and least-square-error methods.	The Accused Instrumentalities perform a method wherein the path parameter information is obtained by at least one estimation technique of the group consisting of a maximum-likelihood estimation algorithm, periodogram, correlatorgram, spectral-based methods, Bartlett beamformers, Capon beamformers, subspace-based techniques, MUSIC (MUltiple SIgnal Classification), ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques), approximation of the maximum-likelihood method based on iterative schemes, SAGE (Space-Alternating Generalized Expectation-maximization), RiMAX (Richter's Maximum Likelihood method), maximum-a-posteriori based methods, Evidence Framework, Bayesian techniques, tracking algorithms, Kalman filtering techniques, enhanced Kalman filtering techniques, particle filtering techniques, and least-square-error methods.
	
	For example, on information and belief, the Accused Instrumentalities perform one or more forms of maximum-likelihood methods based upon iterative schemes:
	
	7.3 Maximum Likelihood (ML) receivers
	
	ML-type of receivers are non-linear in nature. Three types of ML receivers are also identified:
	- ML:
	  - Full-blown joint detection of useful and interference signals in accordance to the ML criterion
	  - Interference parameters that can enable interferer channel estimation and interferer detection at symbol level (e.g. modulation) are needed.
	- Reduced complexity ML (R-ML):
	  - Reduced complexity joint detection of useful and interference modulation symbols in accordance to the ML criterion (e.g. sphere decoding, QR-MLD, MLM, etc.)
	  - Same interference knowledge as for ML
	- Iterative ML and Iterative R-ML:
	  - Iterative MAP detection and decoding of useful and interference signals. Both successive and parallel processing implementations may be applied.
	  - In addition to the interference knowledge needed for ML, interference knowledge that can enable code word demodulation and decoding is needed.
	  - Additionally, assumptions on network coordination may be necessary.
	(3GPP TR 36.866 v12.0.1, § 7.3)

Claim 6

Claim 6	Public Documentation
[6] The method of claim 1, further comprising equalizing the predistorted second signal at the receiver.	The Accused Instrumentalities perform a method comprising equalizing the predistorted second signal at the receiver. For example, the receiver in the Accused Instrumentalities use a frequency domain channel equalizer to process the predistorted second signal, as shown for example as the "equalization" blocks in the following reference receiver:  (https://www.mathworks.com/help/5g/ug/evm-measurement-of-5g-nr-downlink-waveforms.html)

Claim 7

Claim 7	Public Documentation
[7] The method of claim 6, wherein equalizing the predistorted second signal is performed using a joint processing technique in a coordinated multiple-point (CoMP) system.	The Accused Instrumentalities perform a method wherein equalizing the predistorted second signal is performed using a joint processing technique in a coordinated multiple-point (CoMP) system. For example, on information and belief the Accused Instrumentalities perform joint processing in a CoMP system:

Claim 7	Public Documentation
	5 Downlink coordinated multiple point transmission Downlink coordinated multi-point transmission implies dynamic coordination among multiple geographically separated transmission points. 5.1 Terminology and definitions 5.1.1 General terminology - Point: Set of geographically co-located transmit antennas. Note that sectors of the same site correspond to different points. 5.1.3 CoMP categories Each CoMP scheme may be categorized into one of the following categories. - Joint Processing (JP): Data for a UE is available at more than one point in the CoMP cooperating set (definition below) for a time-frequency resource • Joint Transmission (JT): Simultaneous data transmission from multiple points (part of or entire CoMP cooperating set) to a single UE or multiple UEs in a time-frequency resource (3GPP TR 36.819 v11.2.0, § 5.1)

Claim 8

Claim 8	Public Documentation
[8pre] A system for wireless communication comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities comprise a system for wireless communication. For example, the Accused Instrumentalities comprise a system for beamforming 5G NR transmissions between a base station and user equipment (UE) utilizing the multipath transmission environment between the transmitter and receiver. This system is described, for example, in 3GPP standards documents such as TR 38.901 V15.0.0, TS 38.300 V2.0.0, and associated documents, which describe aspects of the operations associated with components of the Accused Instrumentalities.

Claim 8	Public Documentation

4.1 Overall Architecture

An NG-RAN node is either:

- a gNB, providing NR user plane and control plane protocol terminations towards the UE; or
- an ng-eNB, providing E-UTRA user plane and control plane protocol terminations towards the UE.

The gNBs and ng-eNBs are interconnected with each other by means of the Xn interface. The gNBs and ng-eNBs are also connected by means of the NG interfaces to the 5GC, more specifically to the AMF (Access and Mobility Management Function) by means of the NG-C interface and to the UPF (User Plane Function) by means of the NG-U interface (see TS 23.501 [3]).

NOTE: The architecture and the F1 interface for a functional split are defined in TS 38.401 [4].

The NG-RAN architecture is illustrated in Figure 4.1-1 below.

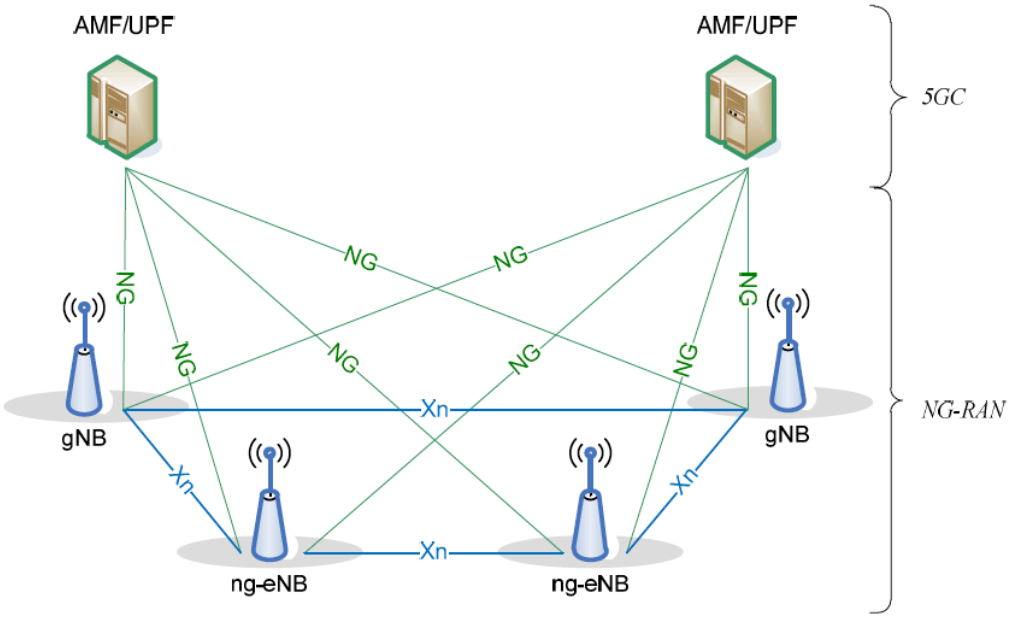
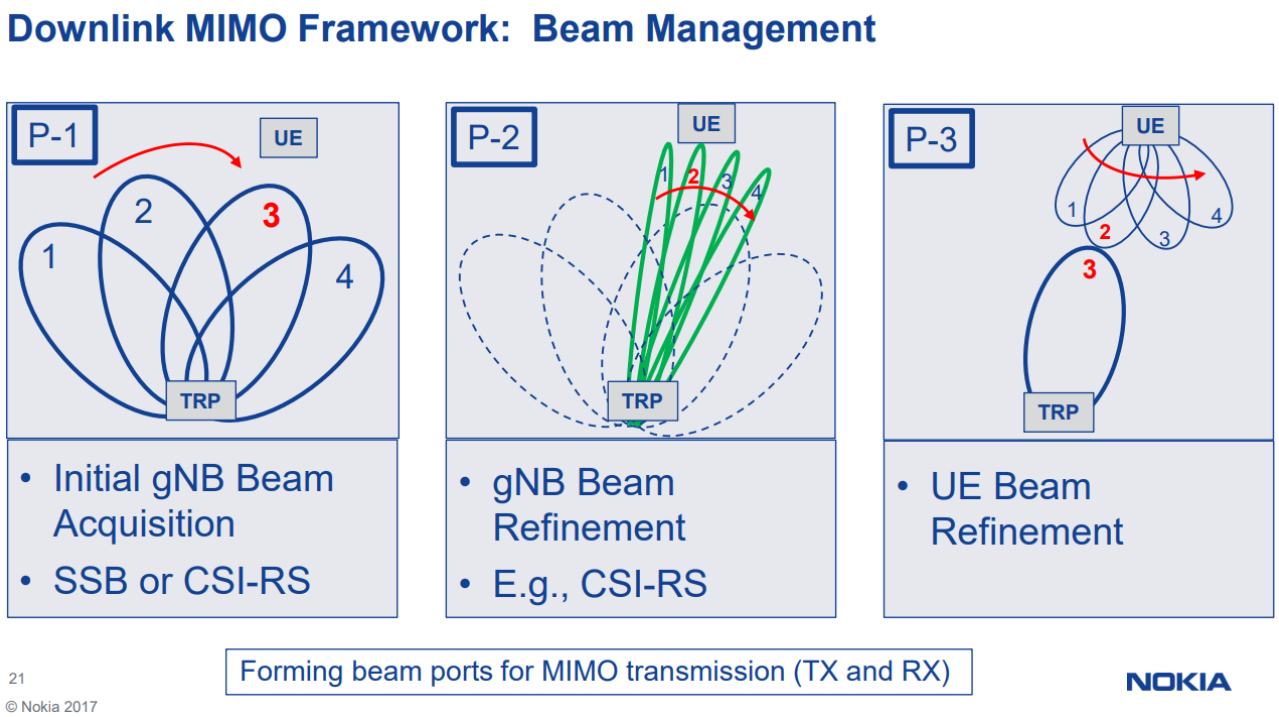


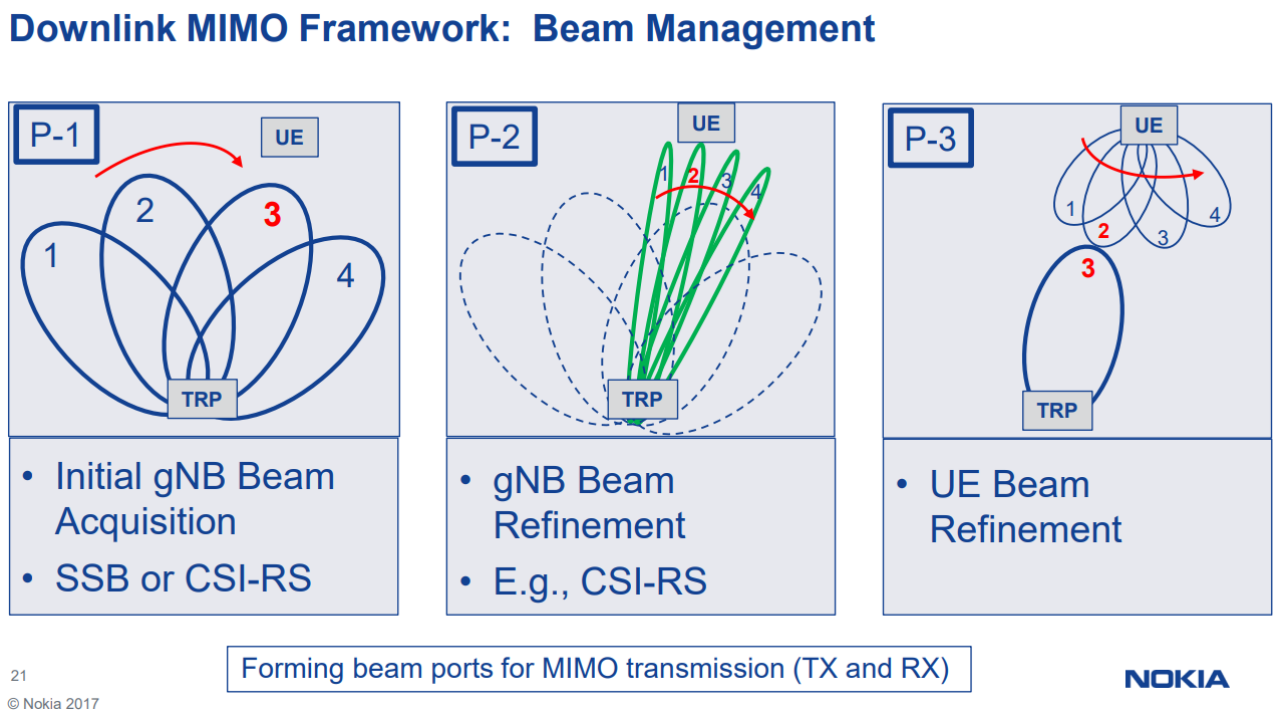
Figure 4.1-1: Overall Architecture

Claim 8	Public Documentation
	(3GPP TS 38.300 v17.2.0, § 4.1) LCS Local Coordinate System LOS Line Of Sight MIMO Multiple-Input-Multiple-Output MPC Multipath Component NLOS Non-LOS (3GPP TR 38.901 v15.0.0, § 3.2) 4. The number of rays per cluster shall be calculated as follows: $M = \min\{\max(M_t M_{\mathrm{AOD}} M_{\mathrm{ZOD}}, 20), M_{\max}\}$ (7.6-8) where: - $M_t = \lceil 4kc_{\mathrm{DS}}B \rceil$ - $M_{\mathrm{AOD}} = \left\lceil 4kc_{\mathrm{ASD}} \frac{\pi \cdot D_h}{180 \cdot \lambda} \right\rceil$ - $M_{\mathrm{ZOD}} = \left\lceil 4kc_{\mathrm{ZSD}} \frac{\pi \cdot D_v}{180 \cdot \lambda} \right\rceil$ - $M_{\max}$ is the upper limit of M, and it should be selected by the user of channel model based on the trade-off between simulation complexity and accuracy. - D_h and D_v are the array size in m in horizontal and vertical dimension, B is bandwidth in Hz, c_{ASD} and c_{ZSD} are the cluster spreads in degrees, and λ is the wavelength. - k is a "sparseness" parameter with value 0.5. It is noted that each MPC may have different AOD, ZOD, and delay. (3GPP TR 38.901 v15.0.0, § 7.6.2.2)

Claim 8	Public Documentation
	Table 7.8-4: Simulation assumptions for calibration for large bandwidth and large antenna array (3GPP TR 38.901 v15.0.0, Table 7.8-4)
[8a] a receiver;	The Accused Instrumentalities comprise a receiver. For example, the UE (such as a cellular handset) contains a receiver that receives the initial transmission as described above and below.

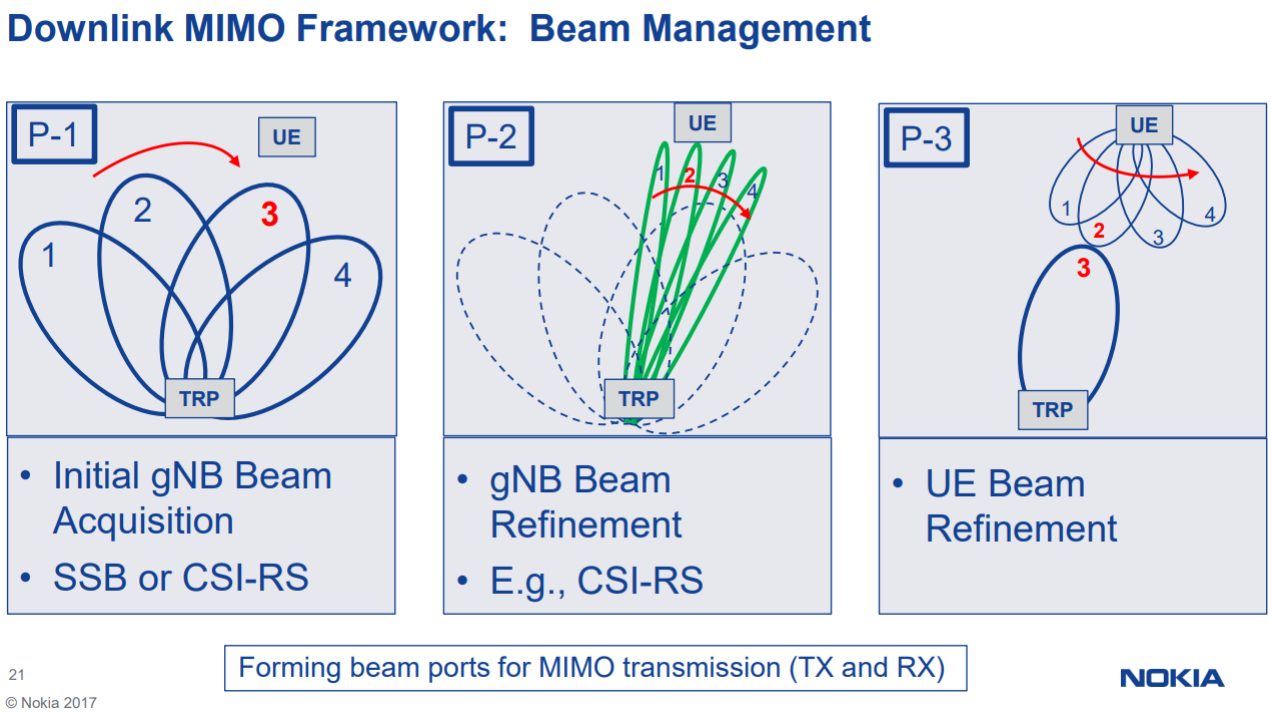
Parameter	Values
Scenarios	UMi-street Canyon
Carrier Frequency	30GHz
Bandwidth	2GHz
BS antenna configurations	M = 8, N = 8, P = 2, M_g = 1, N_g = 4, $d_H = d_V = 0.5\lambda$, $d_{H,g} = d_{V,g} = 4\lambda$
BS port mapping	all 64 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations
The number of rays per cluster	N_{MPC} = 40
Calibration method	Drop multiple users in the multiple cells randomly, and collect the following metrics for each user after attachment.
Metrics	1) CDF of coupling loss (serving cell) 2) Wideband SINR before receiver – determined from RSRP (formula) from CRS port 0 3) CDF of largest (1st) PRB singular values (serving cell) at t=0 plotted in 10*log10 scale

Claim 8	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)
[8b] a transmitter; and	The Accused Instrumentalities comprise a transmitter. For example, the base station contains a transmitter transmits via a narrow-beam antenna to the UE. This is illustrated in the diagrams below as, for example and without limitation, the initial gNB beam (which is one of the plurality of propagation paths).

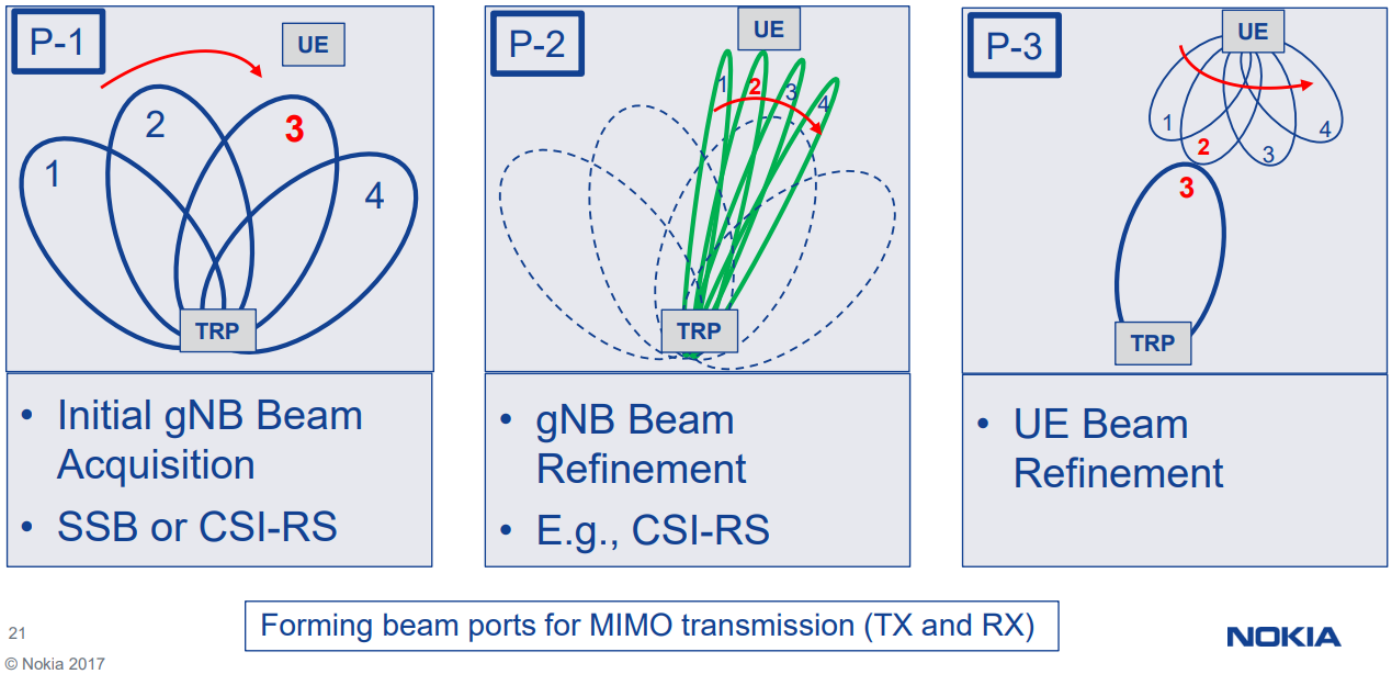
Claim 8	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)
[8c] a plurality of propagation paths formed between the transmitter and the receiver which are capable of carrying a signal transmitted by the transmitter to the receiver,	The Accused Instrumentalities utilize a plurality of propagation paths formed between the transmitter and the receiver which are capable of carrying a signal transmitted by the transmitter to the receiver. For example, the Accused Instrumentalities perform a method for beamforming 5G NR transmissions between a base station and user equipment (UE) utilizing the multipath transmission environment between the transmitter and receiver. This method is described, for example, in 3GPP standards documents such as TR 38.901 V15.0.0, TS 38.300 V2.0.0, and associated documents, which describe aspects of the operations associated with components of the Accused Instrumentalities.

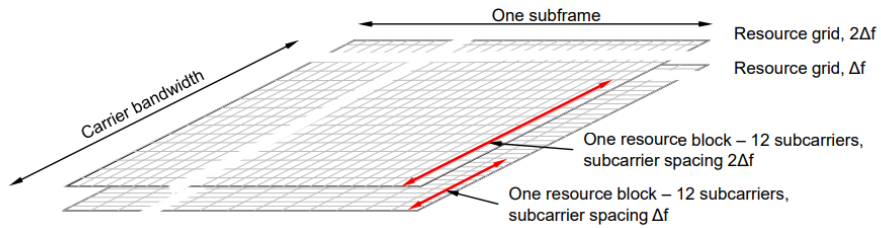
Claim 8	Public Documentation
	LCS Local Coordinate System LOS Line Of Sight MIMO Multiple-Input-Multiple-Output MPC Multipath Component NLOS Non-LOS (3GPP TR 38.901 v15.0.0, § 3.2) 4. The number of rays per cluster shall be calculated as follows: $$M = \min\{\max(M_t M_{\mathrm{AOD}} M_{\mathrm{ZOD}}, 20), M_{\max}\} \quad (7.6\text{-}8)$$ where: - $M_t = \lceil 4kc_{\mathrm{DS}}B \rceil$ - $M_{\mathrm{AOD}} = \left\lceil 4kc_{\mathrm{ASD}} \frac{\pi \cdot D_h}{180 \cdot \lambda} \right\rceil$ - $M_{\mathrm{ZOD}} = \left\lceil 4kc_{\mathrm{ZSD}} \frac{\pi \cdot D_v}{180 \cdot \lambda} \right\rceil$ - $M_{\max}$ is the upper limit of M, and it should be selected by the user of channel model based on the trade-off between simulation complexity and accuracy. - D_h and D_v are the array size in m in horizontal and vertical dimension, B is bandwidth in Hz, c_{ASD} and c_{ZSD} are the cluster spreads in degrees, and λ is the wavelength. - k is a "sparseness" parameter with value 0.5. It is noted that each MPC may have different AOD, ZOD, and delay. (3GPP TR 38.901 v15.0.0, § 7.6.2.2)

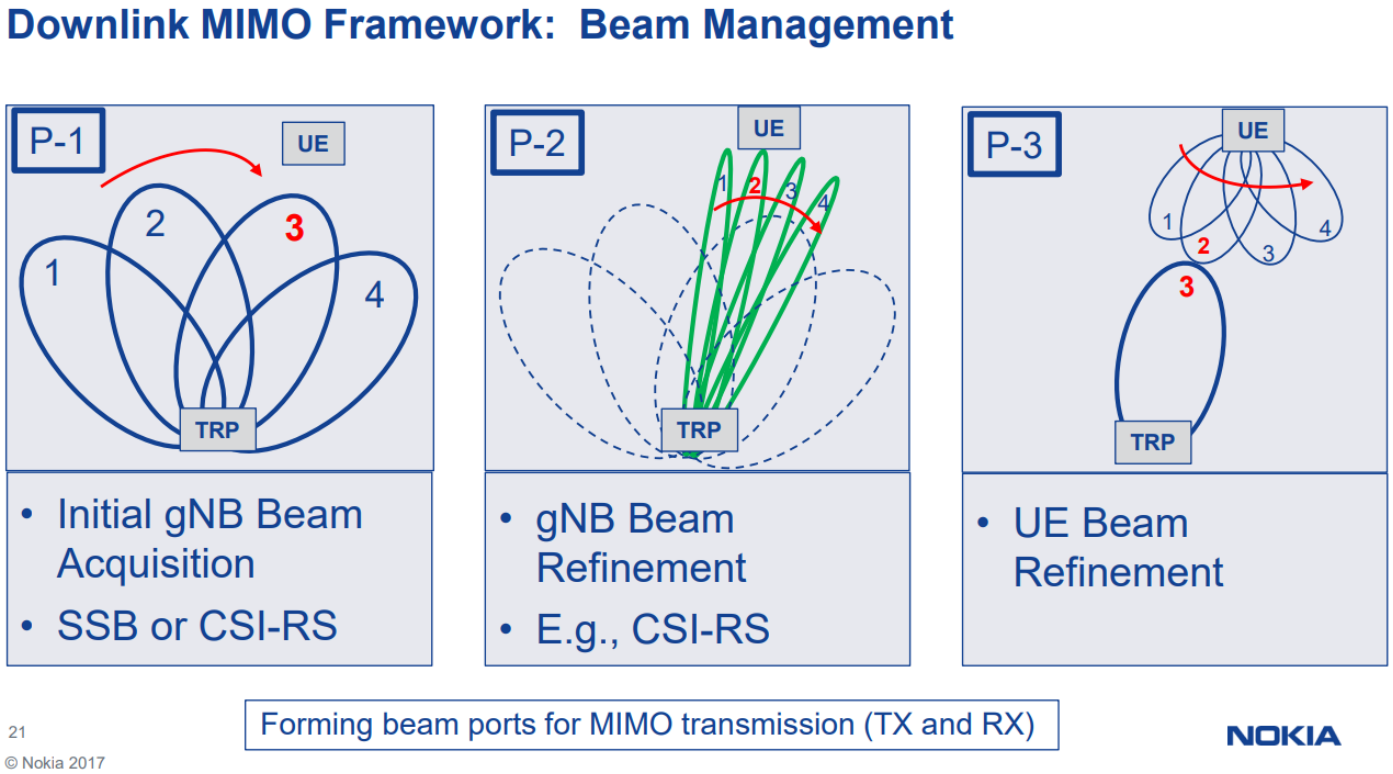
Claim 8	Public Documentation
	Table 7.8-4: Simulation assumptions for calibration for large bandwidth and large antenna array **Parameter** / **Values** Scenarios: UMi-street Canyon Carrier Frequency: 30GHz Bandwidth: 2GHz BS antenna configurations: $M = 8$, $N = 8$, $P = 2$, $M_g = 1$, $N_g = 4$, $d_H = d_V = 0.5\lambda$, $d_{H,g} = d_{V,g} = 4\lambda$ BS port mapping: all 64 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations The number of rays per cluster: $N_{MPC} = 40$ Calibration method: Drop multiple users in the multiple cells randomly, and collect the following metrics for each user after attachment. Metrics: 1) CDF of coupling loss (serving cell) 2) Wideband SINR before receiver – determined from RSRP (formula) from CRS port 0 3) CDF of largest (1st) PRB singular values (serving cell) at t=0 plotted in 10*log10 scale (3GPP TR 38.901 v15.0.0, Table 7.8-4)
[8d] wherein the receiver is configured to receive a first signal that is transmitted along a first propagation path of the plurality of propagation paths from the transmitter,	In the Accused Instrumentalities, the receiver receives a first signal that is transmitted along a first propagation path of the plurality of propagation paths from the transmitter. For example, the UE receives a first signal that is transmitted along a first propagation path of the plurality of propagation paths from the transmitter as described above and below.

Claim 8	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)
[8e] perform a channel estimation based on the first signal to obtain path parameter information of the first propagation path, and	In the Accused Instrumentalities, the receiver performs a channel estimation based on the first signal to obtain path parameter information of the first propagation path. For example, the UE performs link channel state estimation based on the first signal, which includes information that is required by the gNB.

Claim 8	Public Documentation
	5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1)
[8f] send the channel estimation that includes the path parameter information to the transmitter via the first propagation path, and	In the Accused Instrumentalities, the receiver sends the channel estimation that includes the path parameter information to the transmitter via the first propagation path. For example, the UE sends the estimated channel state back to the gNB. In at least TDD mode (as used by 5G NR FR2 with beamforming), the uplink transmission uses the same propagation path (via reciprocity) as the downlink transmission. 5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1)
[8g] wherein the transmitter is configured to predistort a second signal in a time domain, a frequency domain, and a spatial domain according to the channel estimation that is based on the first signal and received from the receiver and	In the Accused Instrumentalities, the transmitter predistorts a second signal in a time domain, a frequency domain, and a spatial domain according to the channel estimation that is based on the first signal and received from the receiver. For example, a 5G NR signal with beamforming is a predistorted signal in time, frequency, and space. For example, applicable time and frequency subcarriers are selected based on the returned CSI, and an appropriate spatial beam refinement is selected based on the returned CSI.

Claim 8	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)

Claim 8	Public Documentation
	Resource grid A GLOBAL INITIATIVE - One resource grid per numerology and antenna port - Resource block = 12 subcarriers - One dimensional unit (unlike LTE) - Resource element = 1 subcarrier in one OFDM symbol  (NR Physical Layer Design: Physical layer structure, numerology and frame structure Workshop on 3GPP submission towards IMT-2020, Brussels, Oct. 24-25, 2018, Havish Koorapaty 3GPP TSG RAN WG1 vice-chairman (Ericsson), available at https://www.3g4g.co.uk/5G/5Gtech_4001_3GPP_5GNR_IMT2020_EvaluationWorkshop_Oct2018/RWS-180007_3GPP%20NR%20Physical%20Layer%20Structure%20IMT2020.pdf). In this illustration, a resource block is placed in a particular subframe (by time) and resource block (by frequency, i.e. subcarriers).
[8h] to transmit the predistorted second signal to the receiver via the first propagation path.	In the Accused Instrumentalities, the transmitter transmits the predistorted second signal to the receiver via the first propagation path. For example, the gNB transmits the beamformed signal as described in the previous element.

Claim 8	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)

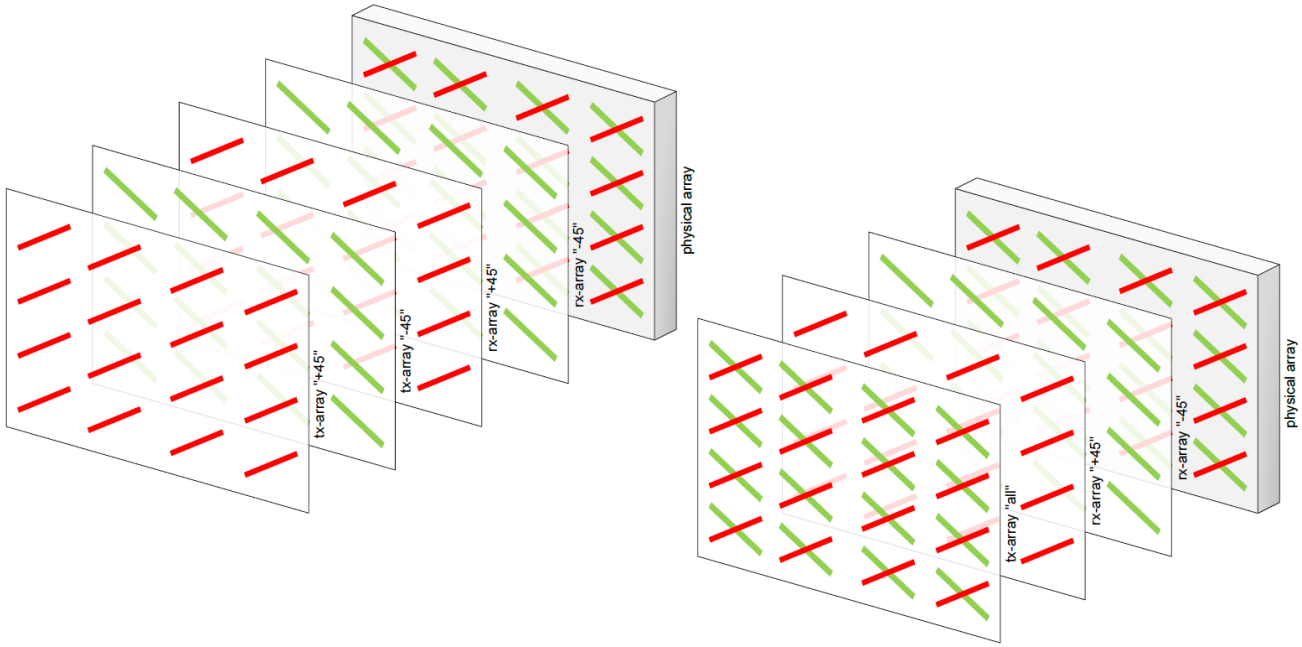
Claim 9

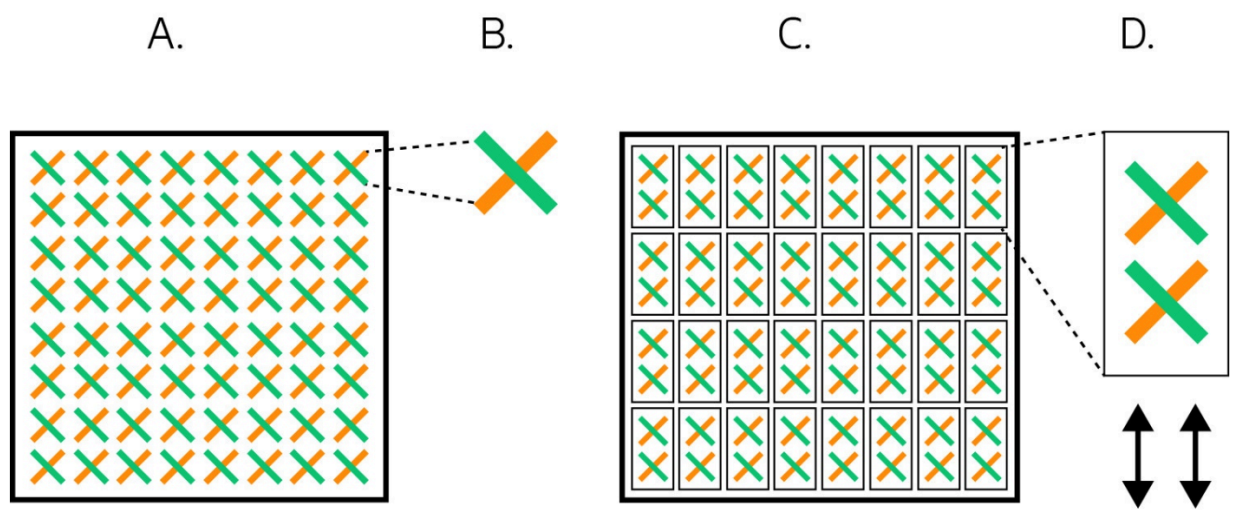
Claim 9	Public Documentation
[9] The system of claim 8, wherein the path parameter information of the first propagation path includes at least one of an estimation of a delay, an estimation of a Doppler frequency, an estima-	The Accused Instrumentalities comprise a system wherein the path parameter information of the first propagation path includes at least one of an estimation of a delay, an estimation of a Doppler frequency, an estimation of a direction of arrival, an estimation of a direction of departure, and an estimation of a complex amplitude of the first propagation path.

Claim 9	Public Documentation
tion of a direction of arrival, an estimation of a direction of departure, and an estimation of a complex amplitude of the first propagation path.	For example, in the Accused Instrumentalities the path parameter information of the first propagation path includes an estimation of a complex amplitude of the first propagation path. For example, the UE receives reference signals, such as CSI-RS reference symbols, and uses the signal to estimate the channel, and reports the channel state information back to the gNB. The propagation path impacts the phase and gain of the signal on each frequency tone which is measured by the UE; the phase and gain may be expressed as a complex number representing the complex amplitude. A 3GPP compliant UE must be able to receive reference signals, such as CSI-RS reference symbols, estimate the channel in the form of a complex amplitude on the OFDM tones, compute and report the estimated channel state to the gNB. 5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1) **Channel State Information Reference Signal (CSI-RS)** As a DL-only signal, the CSI-RS the UE receives is used to estimate the channel and report channel quality information back to the gNB. During MIMO operations, NR uses different antenna approaches based on the carrier frequency. At lower frequencies, the system uses a modest number of active antennas for MU-MIMO and adds FDD operations. In this case, the UE needs the CSI-RS to calculate the CSI and report it back in the UL direction. https://www.techplayon.com/5g-nr-reference-signals-dmrs-ptrssrs-and-csi-rs

Claim 10

Claim 10	Public Documentation
[10] The system of claim 8, wherein the path parameter information of the first propagation path	The Accused Instrumentalities comprise a system wherein the path parameter information of the first propagation path further includes an estimation of a polarization status of the first propagation path.

Claim 10	Public Documentation
further includes an estimation of a polarization status of the first propagation path.	For example, for the channel estimation of the propagation path, the base station transmits reference signals, such as CSI-RS reference signals, from both antenna polarizations. The UE measures the channel state information for signals received from each antenna polarization and reports the channel state information to the base station, to be used for beamforming via distorting the signal at the base station transmitter. The channel state information estimate for the propagation path for each antenna polarization is used for beamforming in 3GPP base stations that utilize dual-polarized antennas. The Accused Instrumentalities 3GPP base station antennas comprise multiple dual-polarized antenna elements: 10.5.5 Model Usage The O-RU antenna model reported by the O-RU consists of RX arrays and TX arrays. RX arrays and TX arrays represent a capability for transmitting/receiving RF signal related to an eAxC and - if beamforming is supported by O-RU on given array - beamforming capability. In this section examples are presented: red and green bars represent array elements of different polarizations, grey box represents physical device, white rectangles represent arrays reported by O-RU.  **Figure 10-7 : Examples of Model Usage – TX as two single-polarization arrays or one cross-polarized array**

Claim 10	Public Documentation
	(O-RAN.WG4.CUS.0-v05.00, Technical Specification, O-RAN Fronthaul Working Group, Control, User and Synchronization Plane Specification) **Antenna array structure** The purpose of using a rectangular antenna array, as shown in section A of Figure 2, is to enable high-gain beams and make it possible to steer those beams over a range of angles. The gain is achieved, in both UL and DL, by constructively combining signals from a number of antenna elements. The more antenna elements there are, the higher the gain. Steerability is achieved by individually controlling the amplitude and phase of smaller parts of the antenna array. This is usually done by dividing the antenna array into so called sub-arrays (groups of non-overlapping elements), as shown in section C of Figure 2, and by applying two dedicated radio chains per sub-array (one per polarization) to enable control, as shown in section D. In this way it is possible to control the direction and other properties of the created antenna array beam.  Figure 2: A typical antenna array (A) is made up of rows and columns of individual dual-polarized antenna elements (B). Antenna arrays can be divided into sub-arrays (C), with each sub-array (D) connected to two radio chains, normally one per polarization. (https://www.ericsson.com/en/reports-and-papers/white-papers/advanced-antenna-systems-for-5g-networks)

Claim 11

Claim 11	Public Documentation

[11] The system of claim 8, wherein the path parameter information is obtained by at least one estimation technique of the group consisting of a maximum likelihood estimation algorithm, periodogram, correlatorgram, spectral-based methods, Bartlett beamformers, Capon beamformers, subspace-based techniques, MUSIC (MUltiple SIgnal Classification), ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques), approximation of the maximum-likelihood method based on iterative schemes, SAGE (Space-Alternating Generalized Expectation-maximization), RiMAX (Richter's Maximum Likelihood method), maximum-a-posteriori based methods, Evidence Framework, Bayesian techniques, tracking algorithms, Kalman filtering techniques, enhanced Kalman filtering techniques, particle filtering techniques, and least-square-error methods.	The Accused Instrumentalities comprise a system wherein the path parameter information is obtained by at least one estimation technique of the group consisting of a maximum likelihood estimation algorithm, periodogram, correlatorgram, spectral-based methods, Bartlett beamformers, Capon beamformers, subspace-based techniques, MUSIC (MUltiple SIgnal Classification), ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques), approximation of the maximum-likelihood method based on iterative schemes, SAGE (Space-Alternating Generalized Expectation-maximization), RiMAX (Richter's Maximum Likelihood method), maximum-a-posteriori based methods, Evidence Framework, Bayesian techniques, tracking algorithms, Kalman filtering techniques, enhanced Kalman filtering techniques, particle filtering techniques, and least-square-error methods.
	
	For example, on information and belief, the Accused Instrumentalities perform one or more forms of maximum-likelihood methods based upon iterative schemes:
	
	7.3 Maximum Likelihood (ML) receivers
	
	ML-type of receivers are non-linear in nature. Three types of ML receivers are also identified:
	- ML:
	  - Full-blown joint detection of useful and interference signals in accordance to the ML criterion
	  - Interference parameters that can enable interferer channel estimation and interferer detection at symbol level (e.g. modulation) are needed.
	- Reduced complexity ML (R-ML):
	  - Reduced complexity joint detection of useful and interference modulation symbols in accordance to the ML criterion (e.g. sphere decoding, QR-MLD, MLM, etc.)
	  - Same interference knowledge as for ML
	- Iterative ML and Iterative R-ML:
	  - Iterative MAP detection and decoding of useful and interference signals. Both successive and parallel processing implementations may be applied.
	  - In addition to the interference knowledge needed for ML, interference knowledge that can enable code word demodulation and decoding is needed.
	  - Additionally, assumptions on network coordination may be necessary.
	(3GPP TR 36.866 v12.0.1, § 7.3)

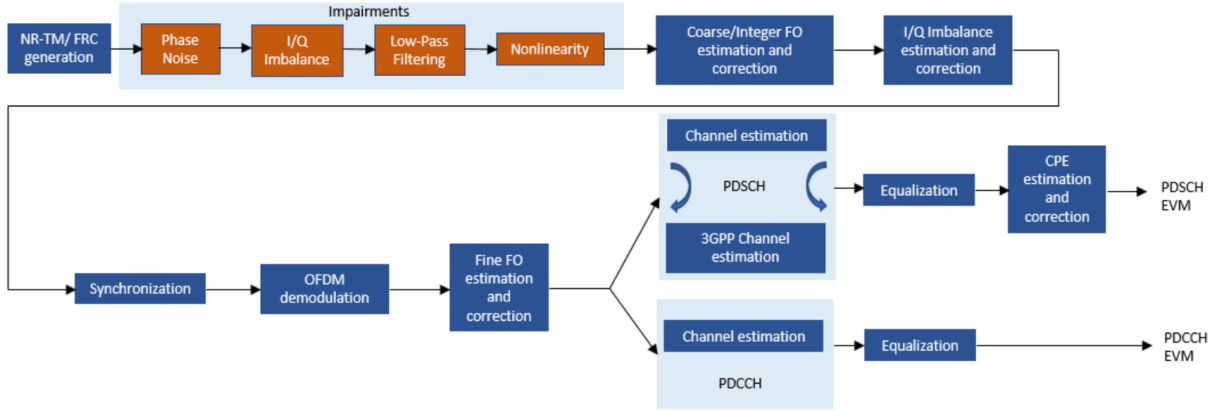
Claim 12

Claim 12	Public Documentation
[12] The system of claim 8, wherein the transmitter and the receiver each comprise multiple antennas in a multiple-input and multiple-output (MIMO) wireless communication system or a single antenna in a single-input and single-output (SISO) wireless communication system.	The Accused Instrumentalities comprise a system wherein the transmitter and the receiver each comprise multiple antennas in a multiple-input and multiple-output (MIMO) wireless communication system or a single antenna in a single-input and single-output (SISO) wireless communication system. For example, the Accused Instrumentalities compress multiple antennas in a MIMO communication system: 5.2 Downlink 5.2.1 Downlink transmission scheme A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU-MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions. The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG). Transmission durations from 2 to 14 symbols in a slot is supported. Aggregation of multiple slots with Transport Block (TB) repetition is supported. (3GPP TS 38.300 v15.5.0, § 5.2.1)

Claim 12	Public Documentation
	5.3 Uplink **5.3.1 Uplink transmission scheme** Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission. For codebook based transmission, the gNB provides the UE with a transmit precoding matrix indication in the DCI. The UE uses the indication to select the PUSCH transmit precoder from the codebook. For non-codebook based transmission, the UE determines its PUSCH precoder based on wideband SRI field from the DCI. A closed loop DMRS based spatial multiplexing is supported for PUSCH. For a given UE, up to 4 layer transmissions are supported. The number of code words is one. When transform precoding is used, only a single MIMO layer transmission is supported. Transmission durations from 1 to 14 symbols in a slot is supported. Aggregation of multiple slots with TB repetition is supported. Two types of frequency hopping are supported, intra-slot frequency hopping, and in case of slot aggregation, inter-slot frequency hopping. PUSCH may be scheduled with DCI on PDCCH, or a semi-static configured grant may be provided over RRC, where two types of operation are supported: - The first PUSCH is triggered with a DCI, with subsequent PUSCH transmissions following the RRC configuration and scheduling received on the DCI, or - The PUSCH is triggered by data arrival to the UE's transmit buffer and the PUSCH transmissions follow the RRC configuration. (3GPP TS 38.300 v15.5.0, § 5.3.1)

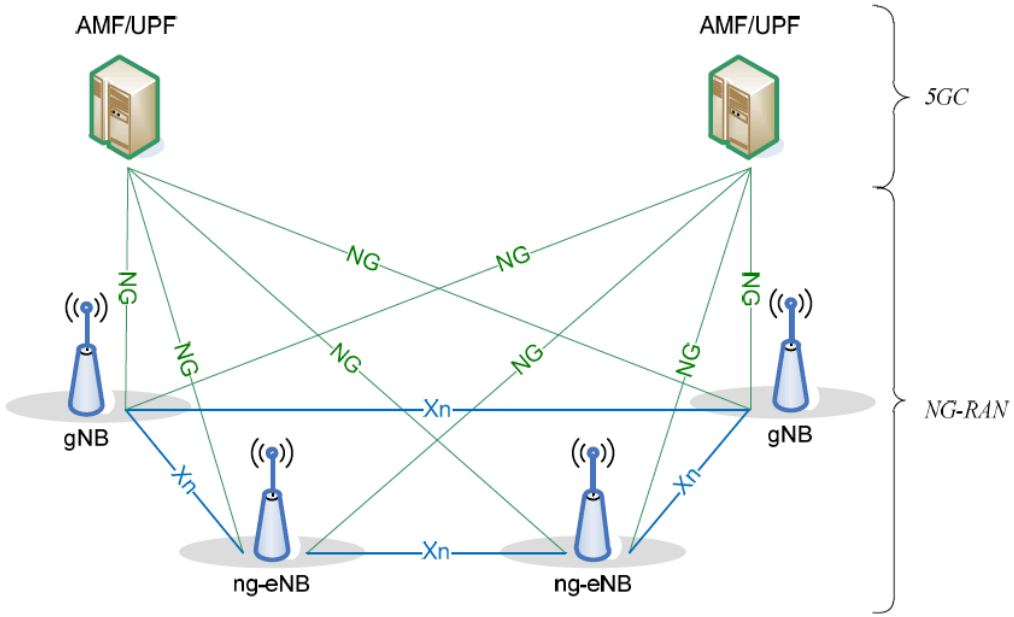
Claim 14

Claim 14	Public Documentation
[14] The system of claim 8, wherein the receiver is further configured to equalize the predistorted second signal.	The Accused Instrumentalities comprise a system wherein the receiver is further configured to equalize the predistorted second signal.

Claim 14	Public Documentation
	For example, the receiver in the Accused Instrumentalities use a frequency domain channel equalizer to process the pre-distorted second signal, as shown for example as the "equalization" blocks in the following reference receiver:  (https://www.mathworks.com/help/5g/ug/evm-measurement-of-5g-nr-downlink-waveforms.html)

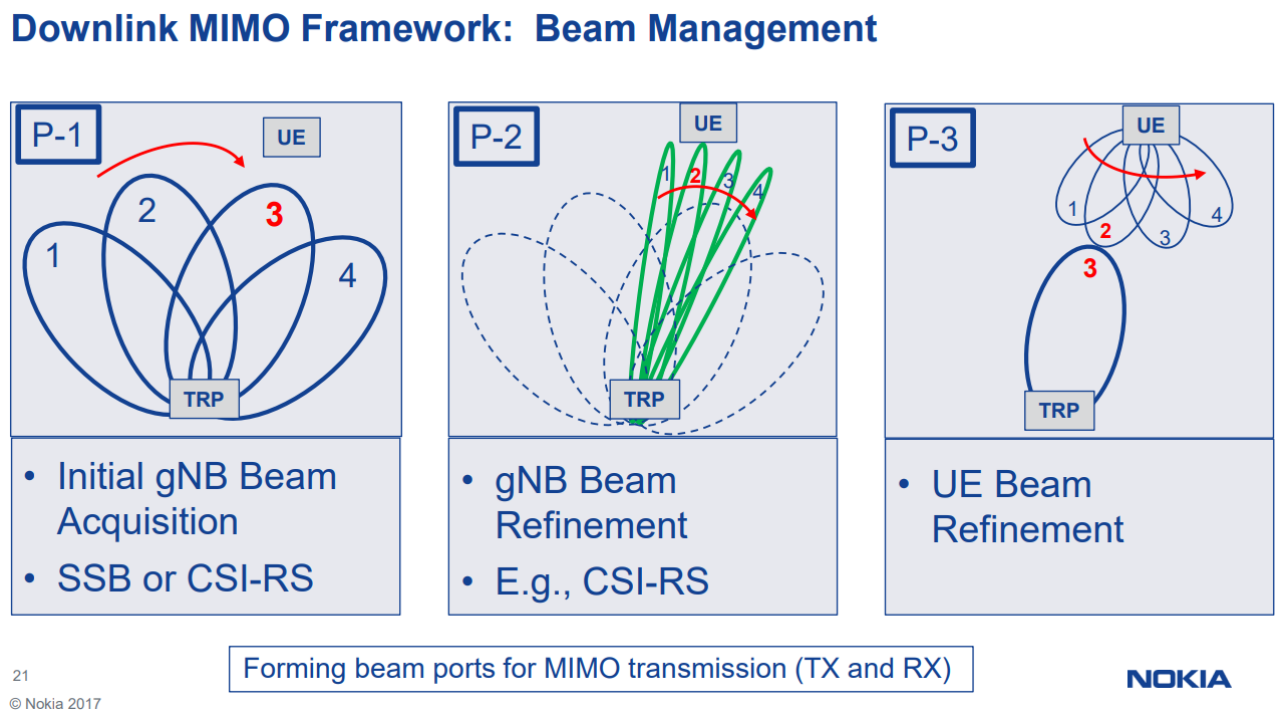
Claim 15

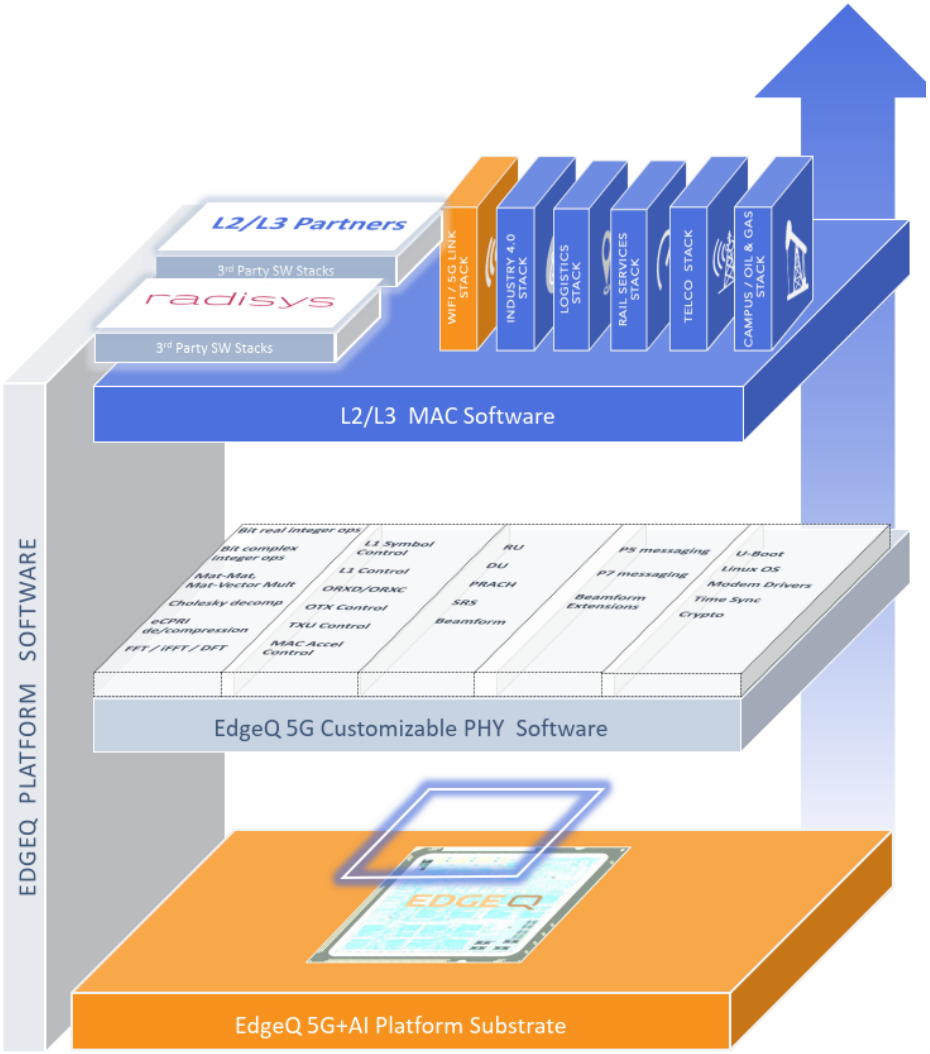
Claim 15	Public Documentation
[15pre] A base station for performing wireless communication with a receiver in a wireless device via a plurality of propagation paths, the base station comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities comprise a base station for performing wireless communication with a receiver in a wireless device via a plurality of propagation paths. For example, the Accused Instrumentalities comprise a base station for beamforming 5G NR transmissions to user equipment (UE) utilizing the multipath transmission environment between the transmitter and receiver. This system is described, for example, in 3GPP standards documents such as TR 38.901 V15.0.0, TS 38.300 V2.0.0, and associated documents, which describe aspects of the operations associated with components of the Accused Instrumentalities.

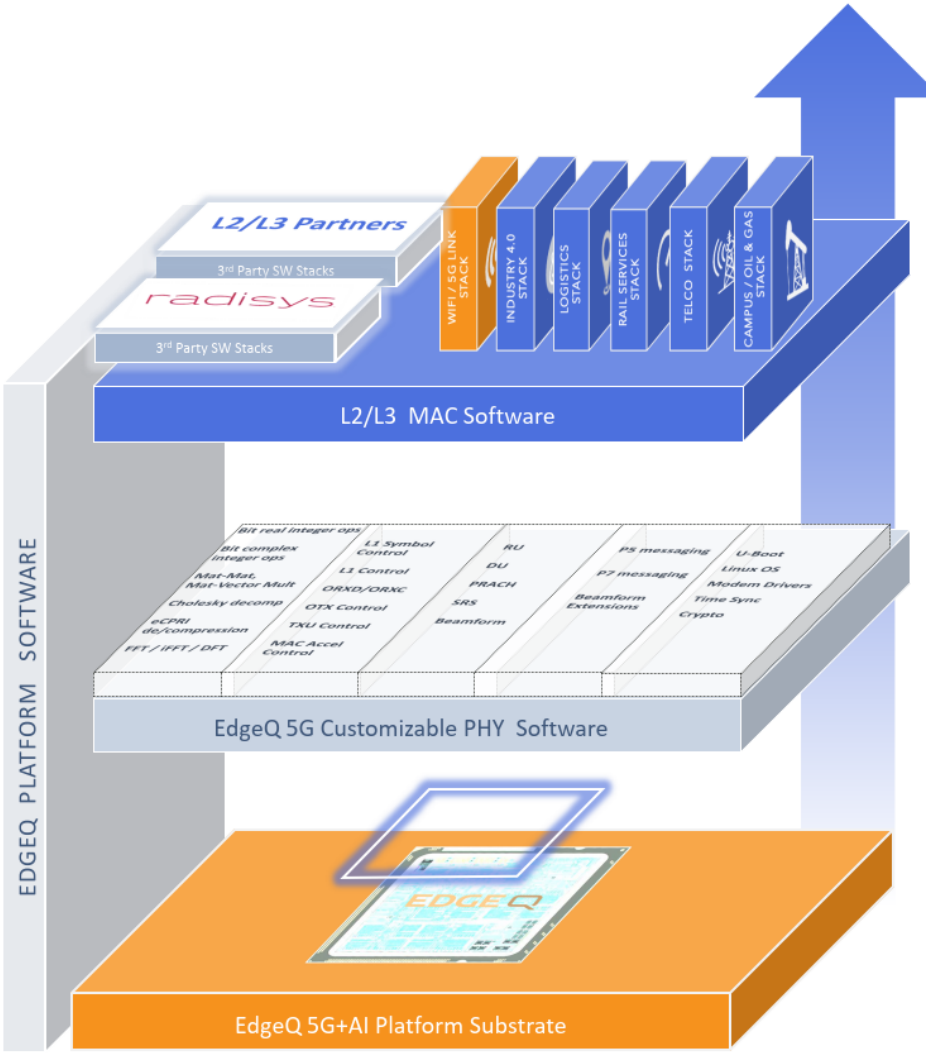
Claim 15	Public Documentation
	4.1 Overall Architecture An NG-RAN node is either: - a gNB, providing NR user plane and control plane protocol terminations towards the UE; or - an ng-eNB, providing E-UTRA user plane and control plane protocol terminations towards the UE. The gNBs and ng-eNBs are interconnected with each other by means of the Xn interface. The gNBs and ng-eNBs are also connected by means of the NG interfaces to the 5GC, more specifically to the AMF (Access and Mobility Management Function) by means of the NG-C interface and to the UPF (User Plane Function) by means of the NG-U interface (see TS 23.501 [3]). NOTE: The architecture and the F1 interface for a functional split are defined in TS 38.401 [4]. The NG-RAN architecture is illustrated in Figure 4.1-1 below.  **Figure 4.1-1: Overall Architecture**

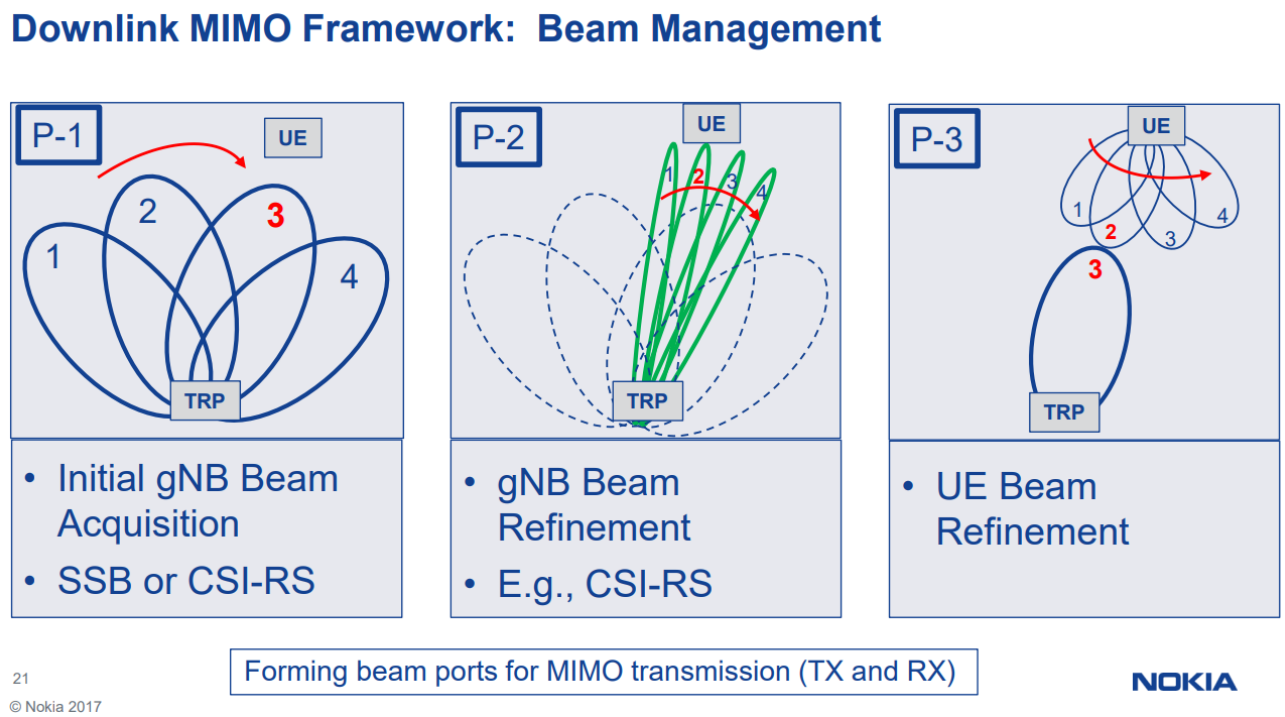
Claim 15	Public Documentation
	(3GPP TS 38.300 v17.2.0, § 4.1) LCS Local Coordinate System LOS Line Of Sight MIMO Multiple-Input-Multiple-Output MPC Multipath Component NLOS Non-LOS (3GPP TR 38.901 v15.0.0, § 3.2) 4. The number of rays per cluster shall be calculated as follows: $M = \min\{\max(M_t M_{\mathrm{AOD}} M_{\mathrm{ZOD}}, 20), M_{\max}\}$ (7.6-8) where: - $M_t = \lceil 4kc_{\mathrm{DS}}B \rceil$ - $M_{\mathrm{AOD}} = \left\lceil 4kc_{\mathrm{ASD}} \frac{\pi \cdot D_h}{180 \cdot \lambda} \right\rceil$ - $M_{\mathrm{ZOD}} = \left\lceil 4kc_{\mathrm{ZSD}} \frac{\pi \cdot D_v}{180 \cdot \lambda} \right\rceil$ - $M_{\max}$ is the upper limit of M, and it should be selected by the user of channel model based on the trade-off between simulation complexity and accuracy. - D_h and D_v are the array size in m in horizontal and vertical dimension, B is bandwidth in Hz, c_{ASD} and c_{ZSD} are the cluster spreads in degrees, and λ is the wavelength. - k is a "sparseness" parameter with value 0.5. It is noted that each MPC may have different AOD, ZOD, and delay. (3GPP TR 38.901 v15.0.0, § 7.6.2.2)

Claim 15	Public Documentation
	Table 7.8-4: Simulation assumptions for calibration for large bandwidth and large antenna array **Parameter** / **Values** Scenarios: UMi-street Canyon Carrier Frequency: 30GHz Bandwidth: 2GHz BS antenna configurations: $M = 8$, $N = 8$, $P = 2$, $M_g = 1$, $N_g = 4$, $d_H = d_V = 0.5\lambda$, $d_{H,g} = d_{V,g} = 4\lambda$ BS port mapping: all 64 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations The number of rays per cluster: $N_{MPC} = 40$ Calibration method: Drop multiple users in the multiple cells randomly, and collect the following metrics for each user after attachment. Metrics: 1) CDF of coupling loss (serving cell) 2) Wideband SINR before receiver – determined from RSRP (formula) from CRS port 0 3) CDF of largest (1st) PRB singular values (serving cell) at t=0 plotted in 10*log10 scale (3GPP TR 38.901 v15.0.0, Table 7.8-4)
[15a] a transmitter;	The Accused Instrumentalities comprise a transmitter. For example, the base station contains a transmitter transmits via a narrow-beam antenna to the UE. This is illustrated in the diagrams below as, for example and without limitation, the initial gNB beam (which is one of the plurality of propagation paths).

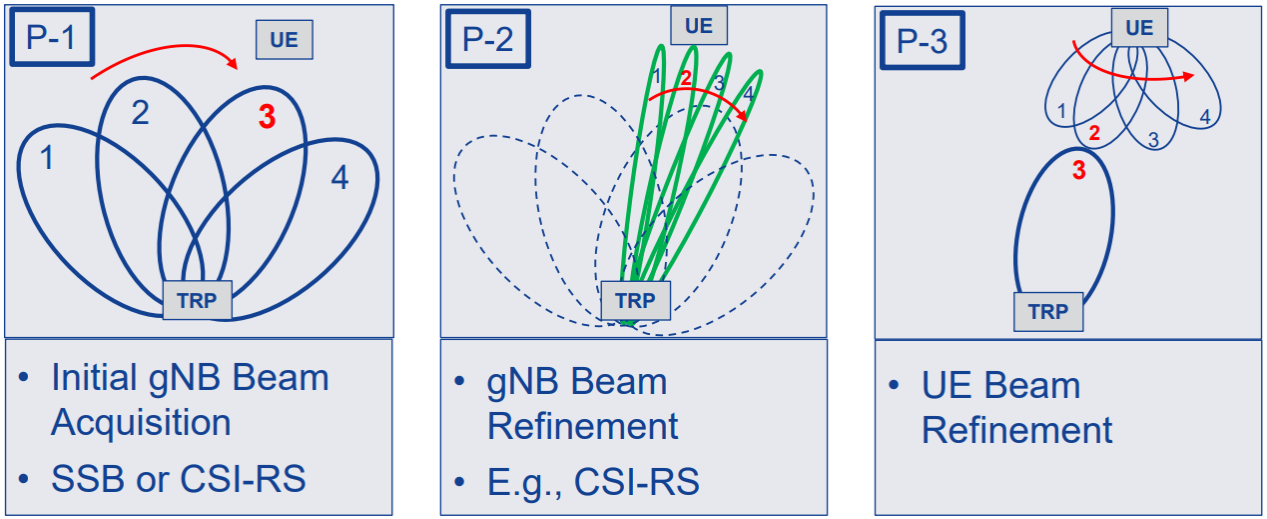
Claim 15	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)
[15b] a computing device; and	The Accused Instrumentalities comprise a computing device. For example, the Accused Instrumentalities comprise one or more chips that implement the 5G NR physical layer, shown for example in the following illustrative drawing:

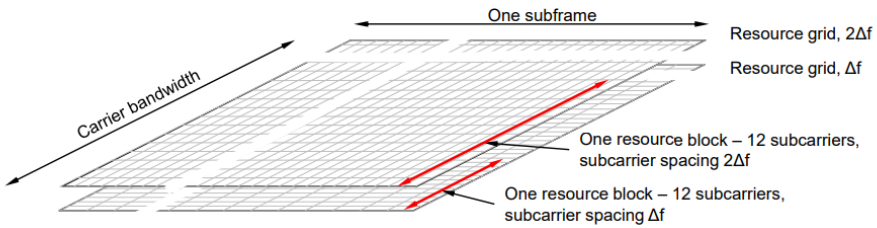
Claim 15	Public Documentation
	 (https://www.5gtechnologyworld.com/how-it-works-base-station-on-a-chip/)
[15c] a computer-readable storage medium having computer-executable instructions stored thereon	The Accused Instrumentalities comprise a computer-readable storage medium having computer-executable instructions stored thereon that are executable by the computing device to perform operations.

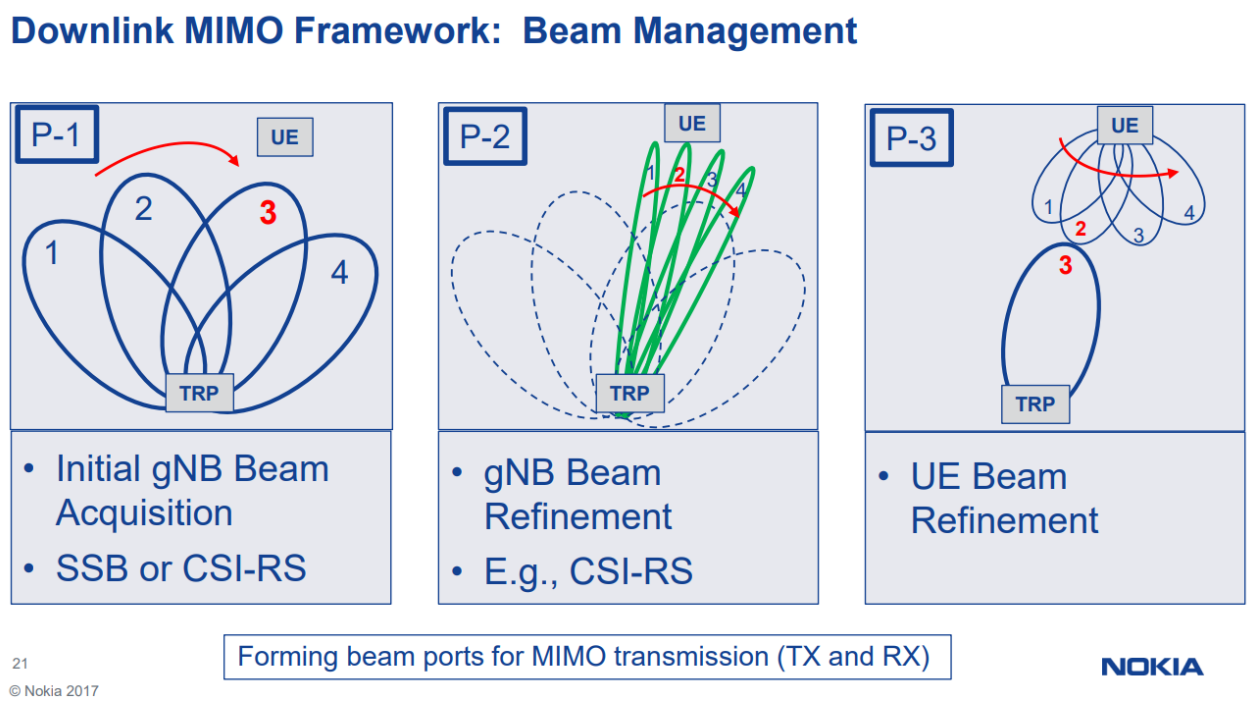
Claim 15	Public Documentation
that are executable by the computing device to perform operations comprising:	For example, the Accused Instrumentalities comprise software, firmware, and/or microcode instructions that implement the 5G NR physical layer, which are stored on a computer-readable medium and executable by the one or more chips, shown for example in the following illustrative drawing:  (https://www.5gtechnologyworld.com/how-it-works-base-station-on-a-chip/)

Claim 15	Public Documentation
[15d] transmitting a first signal from the transmitter to the receiver via a first propagation path of the plurality of propagation paths;	The Accused Instrumentalities transmit a first signal from the transmitter to the receiver via a first propagation path of the plurality of propagation paths. For example, the base station initially transmits via a narrow-beam antenna to the UE. This is illustrated in the diagrams below as, for example and without limitation, the initial gNB beam (which is one of the plurality of propagation paths).  (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)
[15e] receiving a channel estimation based on the first signal, the channel estimation including path parameter information of the first propagation path;	The Accused Instrumentalities receive a channel estimation based on the first signal, the channel estimation including path parameter information of the first propagation path. For example, the UE performs link channel state estimation based on the first signal, which includes information that is required by the gNB.

Claim 15	Public Documentation
	5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1) The UE sends the estimated channel state back to the gNB, which receives the channel estimation. In at least TDD mode (as used by 5G NR FR2 with beamforming), the uplink transmission uses the same propagation path (via reciprocity) as the downlink transmission. 5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1)
[15f] predistorting a second signal in a time domain, a frequency domain, and a spatial domain according to the channel estimation based on the first signal; and	The Accused Instrumentalities predistort a second signal in a time domain, a frequency domain, and a spatial domain according to the channel estimation based on the first signal For example, a 5G NR signal with beamforming is a predistorted signal in time, frequency, and space. For example, applicable time and frequency subcarriers are selected based on the returned CSI, and an appropriate spatial beam refinement is selected based on the returned CSI.

Claim 15	Public Documentation
	Downlink MIMO Framework: Beam Management  21 Forming beam ports for MIMO transmission (TX and RX) NOKIA © Nokia 2017 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)

Claim 15	Public Documentation
	Resource grid - One resource grid per numerology and antenna port - Resource block = 12 subcarriers - One dimensional unit (unlike LTE) - Resource element = 1 subcarrier in one OFDM symbol  (NR Physical Layer Design: Physical layer structure, numerology and frame structure Workshop on 3GPP submission towards IMT-2020, Brussels, Oct. 24-25, 2018, Havish Koorapaty 3GPP TSG RAN WG1 vice-chairman (Ericsson), available at https://www.3g4g.co.uk/5G/5Gtech_4001_3GPP_5GNR_IMT2020_EvaluationWorkshop_Oct2018/RWS-180007_3GPP%20NR%20Physical%20Layer%20Structure%20IMT2020.pdf). In this illustration, a resource block is placed in a particular subframe (by time) and resource block (by frequency, i.e. subcarriers).
[15g] transmitting the predistorted second signal from the transmitter to the receiver via the first propagation path.	The Accused Instrumentalities transmit the predistorted second signal from the transmitter to the receiver via the first propagation path. For example, the gNB transmits the beamformed signal as described in the previous element.

Claim 15	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)

Claim 16

Claim 16	Public Documentation
[16] The base station of claim 15, wherein the path parameter information of the first propagation path includes at least one of an estimation of a delay, an estimation of a Doppler frequency, an estimation of a direction of arrival, an estimation of a direction of departure, an estimation of a complex	The Accused Instrumentalities comprise a base station wherein the path parameter information of the first propagation path includes at least one of an estimation of a delay, an estimation of a Doppler frequency, an estimation of a direction of arrival, an estimation of a direction of departure, an estimation of a complex amplitude of the first propagation path, and an estimation of a polarization status of the first propagation path. For example, in the Accused Instrumentalities the path parameter information of the first propagation path includes an estimation of a complex amplitude of the first propagation path. For example, the UE receives reference signals, such as CSI-RS reference symbols, and uses the signal to estimate the channel, and reports the channel state information back to the gNB.

Claim 16	Public Documentation
amplitude of the first propagation path, and an estimation of a polarization status of the first propagation path.	The propagation path impacts the phase and gain of the signal on each frequency tone which is measured by the UE; the phase and gain may be expressed as a complex number representing the complex amplitude. A 3GPP compliant UE must be able to receive reference signals, such as CSI-RS reference symbols, estimate the channel in the form of a complex amplitude on the OFDM tones, compute and report the estimated channel state to the gNB. 5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1) **Channel State Information Reference Signal (CSI-RS)** As a DL-only signal, the CSI-RS the UE receives is used to estimate the channel and report channel quality information back to the gNB. During MIMO operations, NR uses different antenna approaches based on the carrier frequency. At lower frequencies, the system uses a modest number of active antennas for MU-MIMO and adds FDD operations. In this case, the UE needs the CSI-RS to calculate the CSI and report it back in the UL direction. https://www.techplayon.com/5g-nr-reference-signals-dmrs-ptrssrs-and-csi-rs

Claim 17

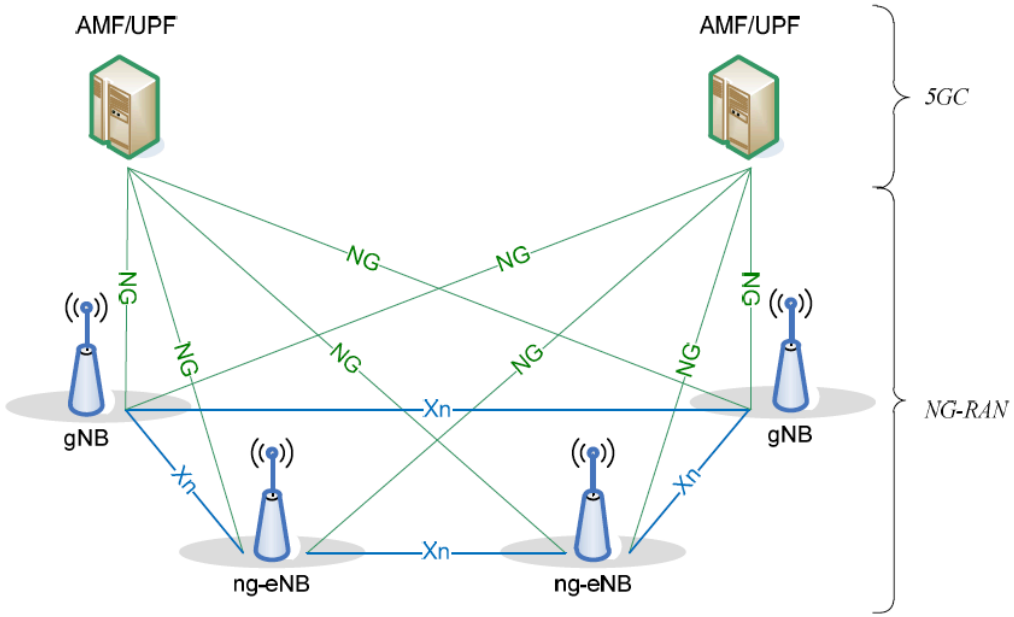
Claim 17	Public Documentation
[17] The base station of claim 15, wherein the transmitter comprises multiple antennas in a multiple-input and multiple-output (MIMO) wireless communication system or a single antenna in a single-input and single-output (SISO) wireless communication system.	The Accused Instrumentalities comprise a base station wherein the transmitter comprises multiple antennas in a multiple-input and multiple-output (MIMO) wireless communication system or a single antenna in a single-input and single-output (SISO) wireless communication system. For example, the Accused Instrumentalities compress multiple antennas in a MIMO communication system:

Claim 17	Public Documentation
	5.2 Downlink 5.2.1 Downlink transmission scheme A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU-MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions. The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG). Transmission durations from 2 to 14 symbols in a slot is supported. Aggregation of multiple slots with Transport Block (TB) repetition is supported. (3GPP TS 38.300 v15.5.0, § 5.2.1)

Claim 17	Public Documentation
	5.3 Uplink 5.3.1 Uplink transmission scheme Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission. For codebook based transmission, the gNB provides the UE with a transmit precoding matrix indication in the DCI. The UE uses the indication to select the PUSCH transmit precoder from the codebook. For non-codebook based transmission, the UE determines its PUSCH precoder based on wideband SRI field from the DCI. A closed loop DMRS based spatial multiplexing is supported for PUSCH. For a given UE, up to 4 layer transmissions are supported. The number of code words is one. When transform precoding is used, only a single MIMO layer transmission is supported. Transmission durations from 1 to 14 symbols in a slot is supported. Aggregation of multiple slots with TB repetition is supported. Two types of frequency hopping are supported, intra-slot frequency hopping, and in case of slot aggregation, inter-slot frequency hopping. PUSCH may be scheduled with DCI on PDCCH, or a semi-static configured grant may be provided over RRC, where two types of operation are supported: - The first PUSCH is triggered with a DCI, with subsequent PUSCH transmissions following the RRC configuration and scheduling received on the DCI, or - The PUSCH is triggered by data arrival to the UE's transmit buffer and the PUSCH transmissions follow the RRC configuration. (3GPP TS 38.300 v15.5.0, § 5.3.1)

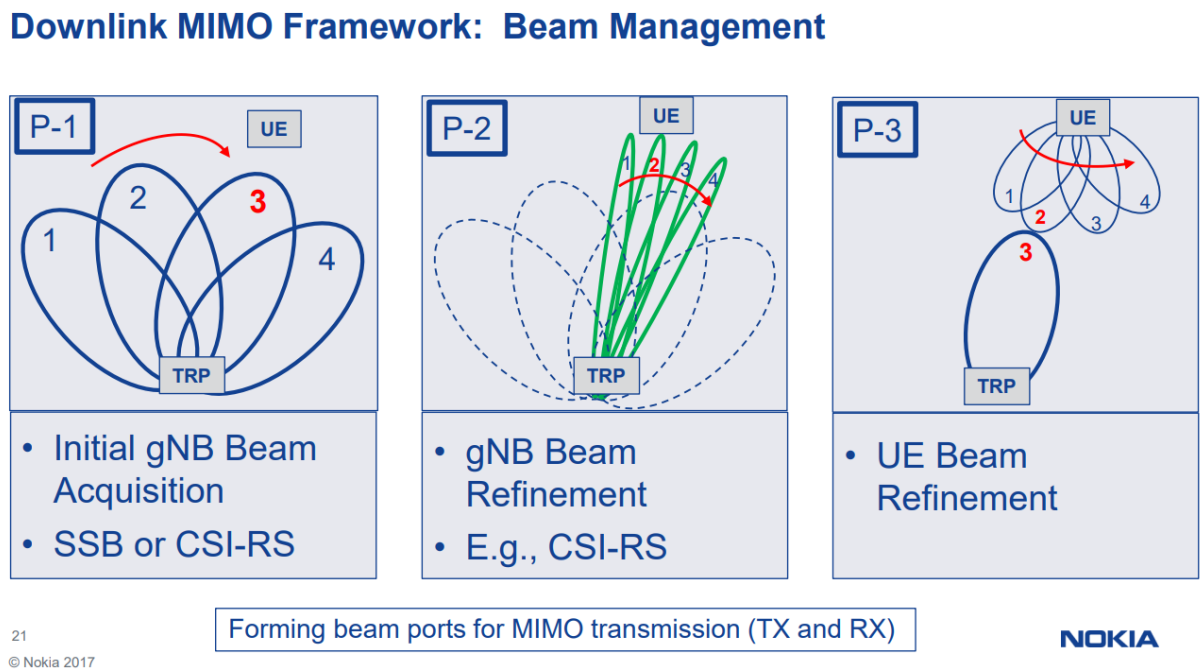
Claim 19

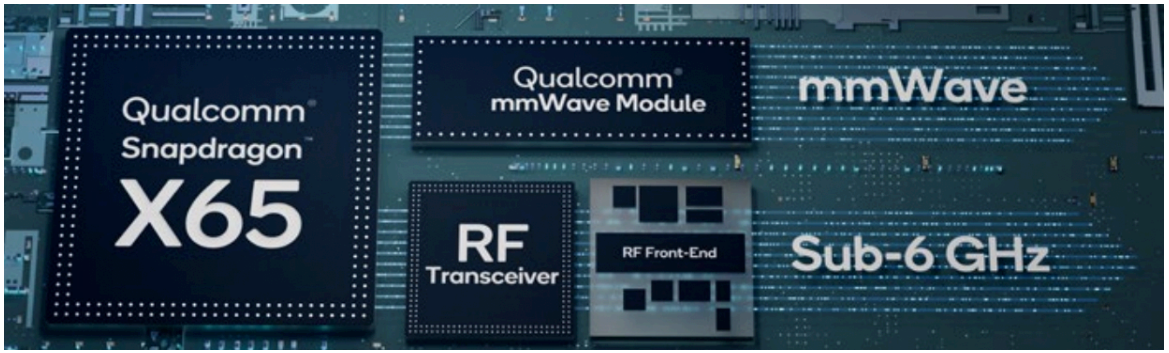
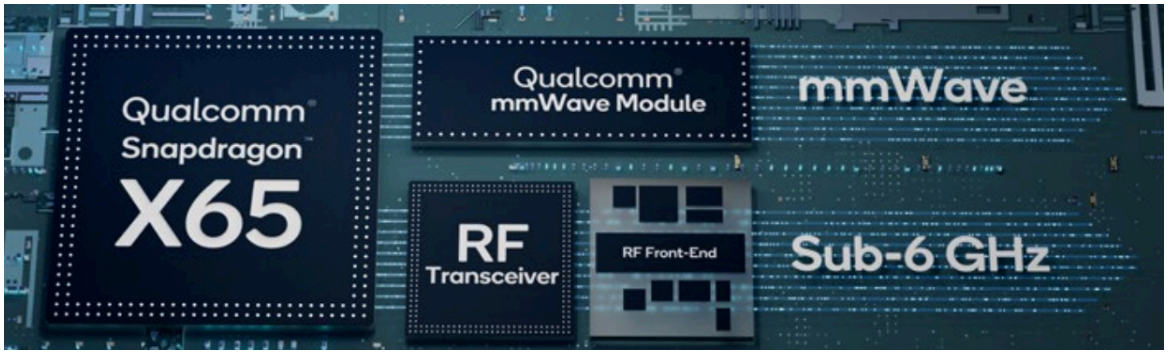
Claim 19	Public Documentation
[19pre] A wireless device for performing wireless communication with a base station with a transmitter via a plurality of propagation paths, the wireless device comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities comprise a wireless device for performing wireless communication with a base station with a transmitter via a plurality of propagation paths. For example, the Accused Instrumentalities include 5g user equipment (UE) such as cellular handsets which communicate with a base station with a transmitter via a plurality of propagation paths: This wireless communication is described, for example, in 3GPP standards documents such as TR 38.901 V15.0.0, TS 38.300 V2.0.0, and associated documents, which describe aspects of the operations associated with components of the Accused Instrumentalities.

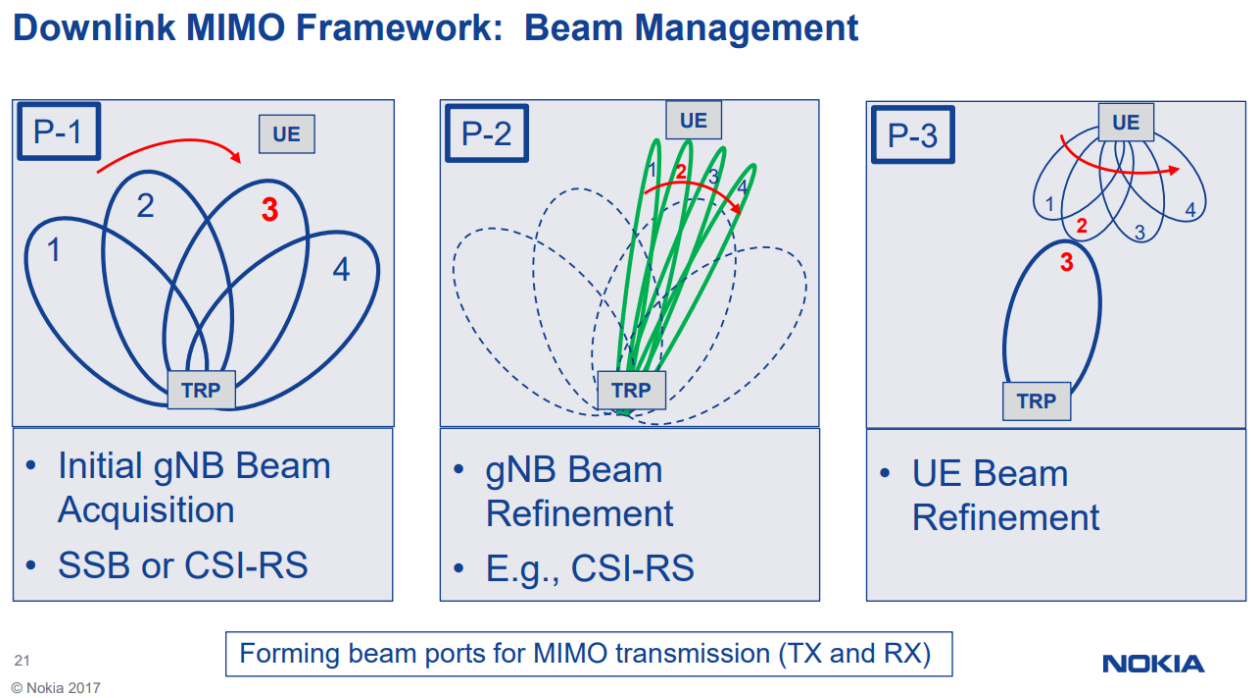
Claim 19	Public Documentation
	4.1 Overall Architecture An NG-RAN node is either: - a gNB, providing NR user plane and control plane protocol terminations towards the UE; or - an ng-eNB, providing E-UTRA user plane and control plane protocol terminations towards the UE. The gNBs and ng-eNBs are interconnected with each other by means of the Xn interface. The gNBs and ng-eNBs are also connected by means of the NG interfaces to the 5GC, more specifically to the AMF (Access and Mobility Management Function) by means of the NG-C interface and to the UPF (User Plane Function) by means of the NG-U interface (see TS 23.501 [3]). NOTE: The architecture and the F1 interface for a functional split are defined in TS 38.401 [4]. The NG-RAN architecture is illustrated in Figure 4.1-1 below.  **Figure 4.1-1: Overall Architecture**

Claim 19	Public Documentation
	(3GPP TS 38.300 v17.2.0, § 4.1) LCS — Local Coordinate System LOS — Line Of Sight MIMO — Multiple-Input-Multiple-Output MPC — Multipath Component NLOS — Non-LOS (3GPP TR 38.901 v15.0.0, § 3.2) 4. The number of rays per cluster shall be calculated as follows: $M = \min\{\max(M_t M_{\mathrm{AOD}} M_{\mathrm{ZOD}}, 20), M_{\max}\}$ (7.6-8) where: - $M_t = \lceil 4kc_{\mathrm{DS}}B \rceil$ - $M_{\mathrm{AOD}} = \left\lceil 4kc_{\mathrm{ASD}} \frac{\pi \cdot D_h}{180 \cdot \lambda} \right\rceil$ - $M_{\mathrm{ZOD}} = \left\lceil 4kc_{\mathrm{ZSD}} \frac{\pi \cdot D_v}{180 \cdot \lambda} \right\rceil$ - $M_{\max}$ is the upper limit of M, and it should be selected by the user of channel model based on the trade-off between simulation complexity and accuracy. - D_h and D_v are the array size in m in horizontal and vertical dimension, B is bandwidth in Hz, c_{ASD} and c_{ZSD} are the cluster spreads in degrees, and λ is the wavelength. - k is a "sparseness" parameter with value 0.5. It is noted that each MPC may have different AOD, ZOD, and delay. (3GPP TR 38.901 v15.0.0, § 7.6.2.2)

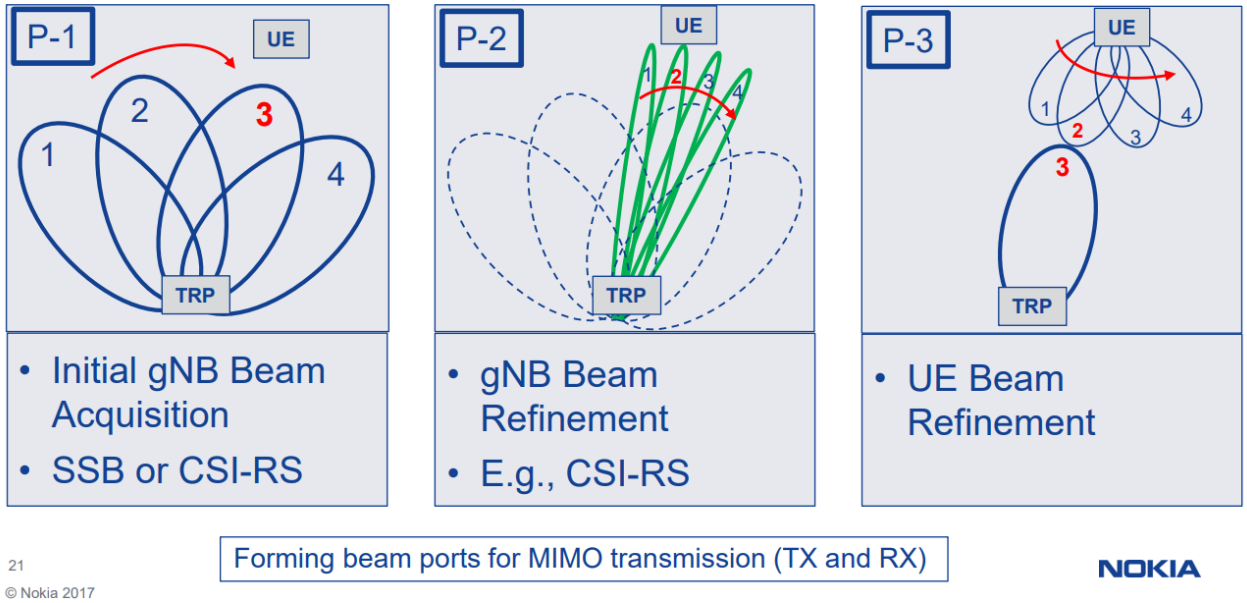
Claim 19	Public Documentation
	Table 7.8-4: Simulation assumptions for calibration for large bandwidth and large antenna array **Parameter** / **Values** Scenarios: UMi-street Canyon Carrier Frequency: 30GHz Bandwidth: 2GHz BS antenna configurations: $M = 8$, $N = 8$, $P = 2$, $M_g = 1$, $N_g = 4$, $d_H = d_V = 0.5\lambda$, $d_{H,g} = d_{V,g} = 4\lambda$ BS port mapping: all 64 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations The number of rays per cluster: $N_{MPC} = 40$ Calibration method: Drop multiple users in the multiple cells randomly, and collect the following metrics for each user after attachment. Metrics: 1) CDF of coupling loss (serving cell) 2) Wideband SINR before receiver – determined from RSRP (formula) from CRS port 0 3) CDF of largest (1st) PRB singular values (serving cell) at t=0 plotted in 10*log10 scale (3GPP TR 38.901 v15.0.0, Table 7.8-4)
[19a] a receiver;	The Accused Instrumentalities comprise a receiver. For example, the UE receives the initial transmission as described above and below.

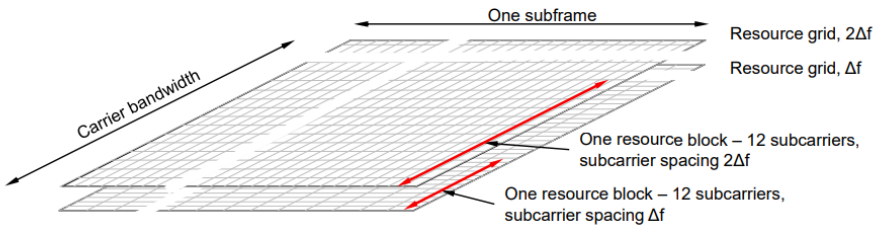
Claim 19	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)
[19b] a computing device; and	The Accused Instrumentalities comprise a computing device. For example, the Accused Instrumentalities comprise one or more chips that implement the 5G NR physical layer, shown for example in the following illustrative drawing:

Claim 19	Public Documentation
	 (https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/prod_brief_qcom_x65.pdf)
[19c] a computer-readable storage medium having computer-executable instructions stored thereon that are executable by the computing device to perform operations comprising:	The Accused Instrumentalities comprise a computer-readable storage medium having computer-executable instructions stored thereon that are executable by the computing device to perform operations. For example, the Accused Instrumentalities comprise software, firmware, and/or microcode instructions that implement the 5G NR physical layer, which are stored on a computer-readable medium and executable by the one or more chips, shown for example in the following illustrative drawing:  (https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/prod_brief_qcom_x65.pdf)
[19d] receiving a first signal at the receiver via a first propagation path of the plurality of propagation paths;	The Accused Instrumentalities receive a first signal at the receiver via a first propagation path of the plurality of propagation paths. For example, the base station initially transmits via a narrow-beam antenna to the UE, and the receiver of the UE receives this first signal. This is illustrated in the diagrams below as, for example and without limitation, the initial gNB beam (which is one of the plurality of propagation paths).

Claim 19	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)
[19e] performing a channel estimation based on the first signal to obtain path parameter information of the first propagation path;	The Accused Instrumentalities perform a channel estimation based on the first signal to obtain path parameter information of the first propagation path. For example, the UE performs link channel state estimation based on the first signal, which includes information that is required by the gNB.

Claim 19	Public Documentation
	5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1)
[19f] sending the channel estimation that includes the path parameter information to the transmitter; and	The Accused Instrumentalities send the channel estimation that includes the path parameter information to the transmitter. For example, the UE sends the estimated channel state back to the gNB. In at least TDD mode (as used by 5G NR FR2 with beamforming), the uplink transmission uses the same propagation path (via reciprocity) as the downlink transmission. 5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1)
[19g] receiving a second signal via the first propagation path, the second signal predistorted in a time domain, a frequency domain, and a spatial domain according to the channel estimation based on the first signal.	The Accused Instrumentalities receive a second signal via the first propagation path, the second signal predistorted in a time domain, a frequency domain, and a spatial domain according to the channel estimation based on the first signal. For example, a 5G NR signal with beamforming is a predistorted signal in time, frequency, and space. For example, applicable time and frequency subcarriers are selected based on the returned CSI, and an appropriate spatial beam refinement is selected based on the returned CSI.

Claim 19	Public Documentation
	 (5G New Radio (NR) : Physical Layer Overview and Performance IEEE Communication Theory Workshop - 2018 Amitabha Ghosh, Nokia Fellow and Head, Radio Interface Group Nokia Bell Labs, May 15th, 2018, at 21)

Claim 19	Public Documentation
	Resource grid - One resource grid per numerology and antenna port - Resource block = 12 subcarriers - One dimensional unit (unlike LTE) - Resource element = 1 subcarrier in one OFDM symbol  (NR Physical Layer Design: Physical layer structure, numerology and frame structure Workshop on 3GPP submission towards IMT-2020, Brussels, Oct. 24-25, 2018, Havish Koorapaty 3GPP TSG RAN WG1 vice-chairman (Ericsson), available at https://www.3g4g.co.uk/5G/5Gtech_4001_3GPP_5GNR_IMT2020_EvaluationWorkshop_Oct2018/RWS-180007_3GPP%20NR%20Physical%20Layer%20Structure%20IMT2020.pdf). In this illustration, a resource block is placed in a particular subframe (by time) and resource block (by frequency, i.e. subcarriers).

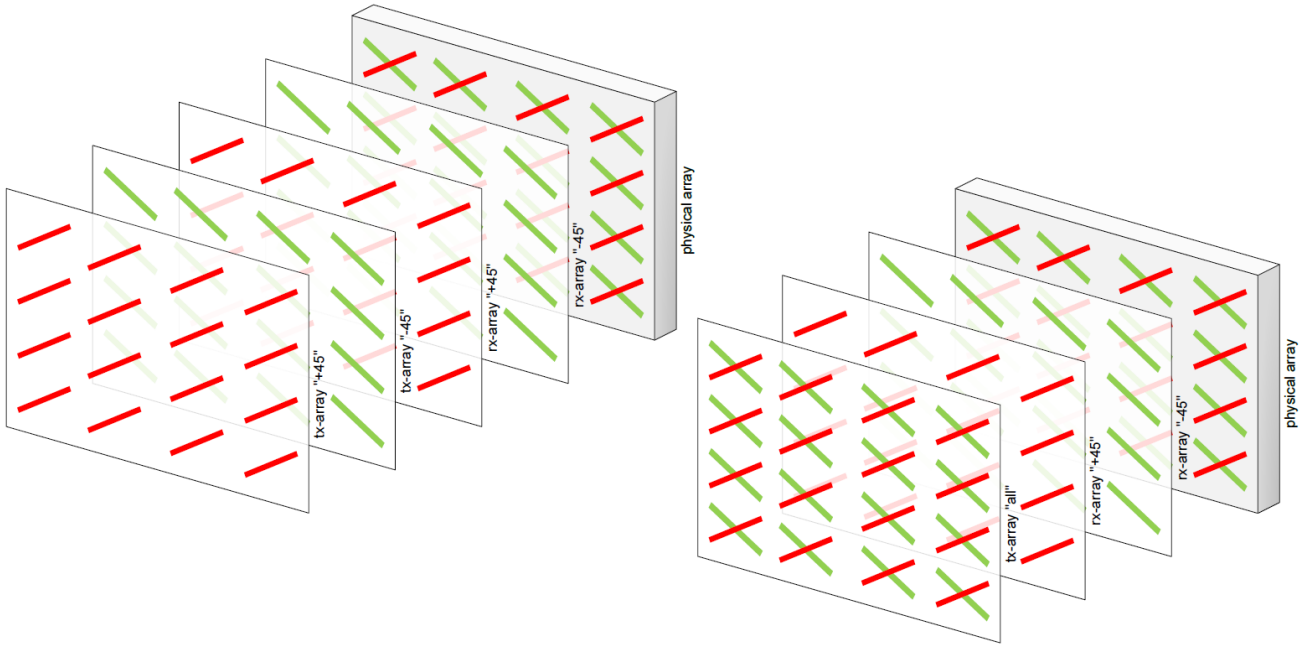
Claim 20

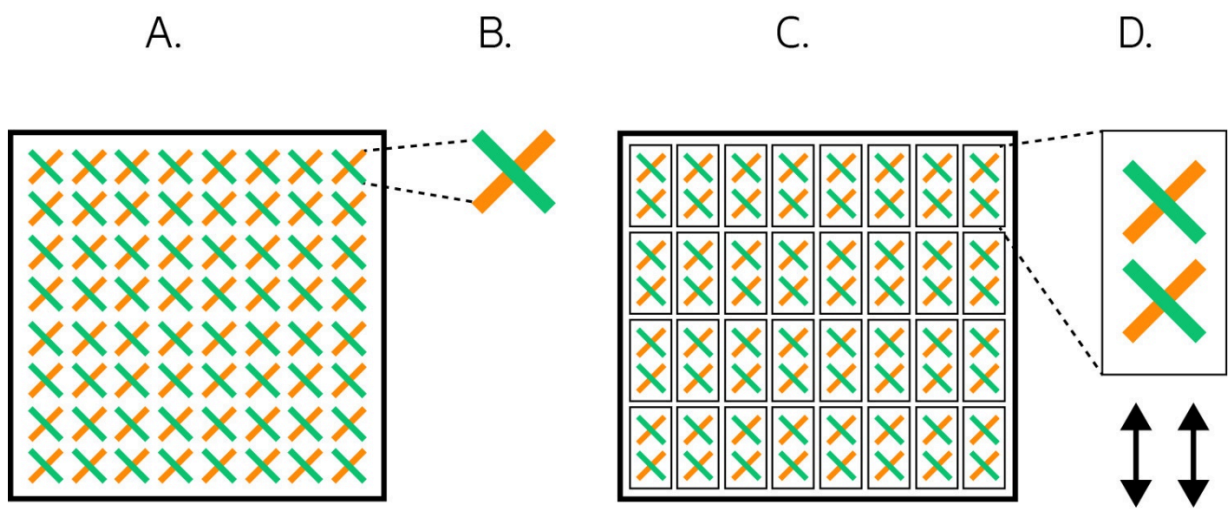
Claim 20	Public Documentation
[20] The wireless device of claim 19, wherein the path parameter information of the first propagation path includes at least one of an estimation of a delay, an estimation of a Doppler frequency, an estimation of a direction of arrival, an estimation	The Accused Instrumentalities comprise a wireless device wherein the path parameter information of the first propagation path includes at least one of an estimation of a delay, an estimation of a Doppler frequency, an estimation of a direction of arrival, an estimation of a direction of departure, and an estimation of a complex amplitude of the first propagation path. For example, in the Accused Instrumentalities the path parameter information of the first propagation path includes an estimation of a complex amplitude of the first propagation path. For example, the UE receives reference signals, such as CSI-

Claim 20	Public Documentation
of a direction of departure, and an estimation of a complex amplitude of the first propagation path.	RS reference symbols, and uses the signal to estimate the channel, and reports the channel state information back to the gNB. The propagation path impacts the phase and gain of the signal on each frequency tone which is measured by the UE; the phase and gain may be expressed as a complex number representing the complex amplitude. A 3GPP compliant UE must be able to receive reference signals, such as CSI-RS reference symbols, estimate the channel in the form of a complex amplitude on the OFDM tones, compute and report the estimated channel state to the gNB. 5.2.5 Physical layer procedures 5.2.5.1 Link adaptation Link adaptation (AMC: adaptive modulation and coding) with various modulation schemes and channel coding rates is applied to the PDSCH. The same coding and modulation is applied to all groups of resource blocks belonging to the same L2 PDU scheduled to one user within one TTI and within a MIMO codeword. For channel state estimation purposes, the UE may be configured to measure CSI-RS and estimate the downlink channel state based on the CSI-RS measurements. The UE feeds the estimated channel state back to the gNB to be used in link adaptation. (3GPP TS 38.200 v2.0.0, § 5.2.5.1) **Channel State Information Reference Signal (CSI-RS)** As a DL-only signal, the CSI-RS the UE receives is used to estimate the channel and report channel quality information back to the gNB. During MIMO operations, NR uses different antenna approaches based on the carrier frequency. At lower frequencies, the system uses a modest number of active antennas for MU-MIMO and adds FDD operations. In this case, the UE needs the CSI-RS to calculate the CSI and report it back in the UL direction. https://www.techplayon.com/5g-nr-reference-signals-dmrs-ptrssrs-and-csi-rs

Claim 21

Claim 21	Public Documentation
[21] The wireless device of claim 20, wherein the path parameter information of the first propagation path further includes an estimation of a polarization status of the first propagation path.	The Accused Instrumentalities comprise a wireless device wherein the path parameter information of the first propagation path further includes an estimation of a polarization status of the first propagation path. For example, for the channel estimation of the propagation path, the base station transmits reference signals, such as CSI-RS reference signals, from both antenna polarizations. The UE measures the channel state information for signals received

Claim 21	Public Documentation
	from each antenna polarization and reports the channel state information to the base station, to be used for beamforming via distorting the signal at the base station transmitter. The channel state information estimate for the propagation path for each antenna polarization is used for beamforming in 3GPP base stations that utilize dual-polarized antennas. The Accused Instrumentalities 3GPP base station antennas comprise multiple dual-polarized antenna elements: **10.5.5 Model Usage** The O-RU antenna model reported by the O-RU consists of RX arrays and TX arrays. RX arrays and TX arrays represent a capability for transmitting/receiving RF signal related to an eAxC and - if beamforming is supported by O-RU on given array - beamforming capability. In this section examples are presented: red and green bars represent array elements of different polarizations, grey box represents physical device, white rectangles represent arrays reported by O-RU.  **Figure 10-7 : Examples of Model Usage – TX as two single-polarization arrays or one cross-polarized array** (O-RAN.WG4.CUS.0-v05.00, Technical Specification, O-RAN Fronthaul Working Group, Control, User and Synchronization Plane Specification)

Claim 21	Public Documentation
	Antenna array structure The purpose of using a rectangular antenna array, as shown in section A of Figure 2, is to enable high-gain beams and make it possible to steer those beams over a range of angles. The gain is achieved, in both UL and DL, by constructively combining signals from a number of antenna elements. The more antenna elements there are, the higher the gain. Steerability is achieved by individually controlling the amplitude and phase of smaller parts of the antenna array. This is usually done by dividing the antenna array into so called sub-arrays (groups of non-overlapping elements), as shown in section C of Figure 2, and by applying two dedicated radio chains per sub-array (one per polarization) to enable control, as shown in section D. In this way it is possible to control the direction and other properties of the created antenna array beam.  Figure 2: A typical antenna array (A) is made up of rows and columns of individual dual-polarized antenna elements (B). Antenna arrays can be divided into sub-arrays (C), with each sub-array (D) connected to two radio chains, normally one per polarization. (https://www.ericsson.com/en/reports-and-papers/white-papers/advanced-antenna-systems-for-5g-networks)

Claim 22

Claim 22	Public Documentation

[22] The wireless device of claim 19, wherein the path parameter information is obtained by at least one estimation technique of the group consisting of a maximum likelihood estimation algorithm, periodogram, correlatorgram, spectral-based methods, Bartlett beamformers, Capon beamformers, subspace-based techniques, MUSIC (MUltiple SIgnal Classification), ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques), approximation of the maximum-likelihood method based on iterative schemes, SAGE (Space-Alternating Generalized Expectation-maximization), RiMAX (Richter's Maximum Likelihood method), maximum-a-posteriori based methods, Evidence Framework, Bayesian techniques, tracking algorithms, Kalman filtering techniques, enhanced Kalman filtering techniques, particle filtering techniques, and least-square-error methods.	The Accused Instrumentalities comprise a wireless device wherein the path parameter information is obtained by at least one estimation technique of the group consisting of a maximum likelihood estimation algorithm, periodogram, correlatorgram, spectral-based methods, Bartlett beamformers, Capon beamformers, subspace-based techniques, MUSIC (MUltiple SIgnal Classification), ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques), approximation of the maximum-likelihood method based on iterative schemes, SAGE (Space-Alternating Generalized Expectation-maximization), RiMAX (Richter's Maximum Likelihood method), maximum-a-posteriori based methods, Evidence Framework, Bayesian techniques, tracking algorithms, Kalman filtering techniques, enhanced Kalman filtering techniques, particle filtering techniques, and least-square-error methods.
	
	For example, on information and belief, the Accused Instrumentalities perform one or more forms of maximum-likelihood methods based upon iterative schemes:
	
	7.3 Maximum Likelihood (ML) receivers
	
	ML-type of receivers are non-linear in nature. Three types of ML receivers are also identified:
	- ML:
	  - Full-blown joint detection of useful and interference signals in accordance to the ML criterion
	  - Interference parameters that can enable interferer channel estimation and interferer detection at symbol level (e.g. modulation) are needed.
	- Reduced complexity ML (R-ML):
	  - Reduced complexity joint detection of useful and interference modulation symbols in accordance to the ML criterion (e.g. sphere decoding, QR-MLD, MLM, etc.)
	  - Same interference knowledge as for ML
	- Iterative ML and Iterative R-ML:
	  - Iterative MAP detection and decoding of useful and interference signals. Both successive and parallel processing implementations may be applied.
	  - In addition to the interference knowledge needed for ML, interference knowledge that can enable code word demodulation and decoding is needed.
	  - Additionally, assumptions on network coordination may be necessary.
	(3GPP TR 36.866 v12.0.1, § 7.3)

Claim 23

Claim 23	Public Documentation
[23] The wireless device of claim 19, wherein the receiver comprises multiple antennas in a multiple-input and multiple-output (MIMO) wireless communication system or a single antenna in a single-input and single-output (SISO) wireless communication system.	The Accused Instrumentalities comprise a wireless device wherein the receiver comprises multiple antennas in a multiple-input and multiple-output (MIMO) wireless communication system or a single antenna in a single-input and single-output (SISO) wireless communication system. For example, the Accused Instrumentalities compress multiple antennas in a MIMO communication system: **5.2 Downlink** **5.2.1 Downlink transmission scheme** A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU-MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions. The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG). Transmission durations from 2 to 14 symbols in a slot is supported. Aggregation of multiple slots with Transport Block (TB) repetition is supported. (3GPP TS 38.300 v15.5.0, § 5.2.1)

Claim 23	Public Documentation
	5.3 Uplink 5.3.1 Uplink transmission scheme Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission. For codebook based transmission, the gNB provides the UE with a transmit precoding matrix indication in the DCI. The UE uses the indication to select the PUSCH transmit precoder from the codebook. For non-codebook based transmission, the UE determines its PUSCH precoder based on wideband SRI field from the DCI. A closed loop DMRS based spatial multiplexing is supported for PUSCH. For a given UE, up to 4 layer transmissions are supported. The number of code words is one. When transform precoding is used, only a single MIMO layer transmission is supported. Transmission durations from 1 to 14 symbols in a slot is supported. Aggregation of multiple slots with TB repetition is supported. Two types of frequency hopping are supported, intra-slot frequency hopping, and in case of slot aggregation, inter-slot frequency hopping. PUSCH may be scheduled with DCI on PDCCH, or a semi-static configured grant may be provided over RRC, where two types of operation are supported: - The first PUSCH is triggered with a DCI, with subsequent PUSCH transmissions following the RRC configuration and scheduling received on the DCI, or - The PUSCH is triggered by data arrival to the UE's transmit buffer and the PUSCH transmissions follow the RRC configuration. (3GPP TS 38.300 v15.5.0, § 5.3.1)