Ryerson University
Department of Electrical
& Computer Engineering
Faculty of Engineering & Architectural Science

Course Title:	Cellular Mobile Communication
Course Number:	ELE 815
Semester/Year (e.g.F2016)	Winter 2017

Instructor:	Professor Anpalagan

Assignment/Lab Number:	3
Assignment/Lab Title:	Final Report

Submission Date:	
Due Date:	

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Introduction

The following report discusses the state of the 5G standard as it appears to date in the academic setting. 5G is currently in its research phase and the specifications for its implementation are expected to be finalized in 2020 before roll-out. This document aims to define the key technologies that will be incorporated into 5G and what types of challenges they present. Possible solutions to these problems are also outlined. This document is divided into separate sections for standardization, mmWave, 5G signaling, channel models, MIMO, and small cell. The last section briefly outlines the proposed 5G simulation approach that will be taken for further research in the near future.

Standardization of 5G

The evidence to support the standardization of 5G comes from variety of sources. One report released by Cisco called the visual network index that is annually published suggests that the current large amount of data requirement comes from video streaming, smartphones and tablets. It has been claimed that the data driven [1] by these current demands of the existing network capacity will not be able to cope by the year 2020. It is mention in this article[20] that the average mobile user will be a downloading a staggering amount of data at around 1 terabyte per year by 2020.Where currently in 2012 most of this data usage comes from video content [17][21]. The current growth of the data usage for wireless networks in 2010 was around 3 Exabyte's and by the year 2020 it would exceed 500 Exabyte's mark[1]. Furthermore the historical increase in the data usage shows an exponential growth characteristic which will be further faced by new data usage challenges of 5G's applications such as coming from internet of things, virtualization, and 3D video. It should be noted that although the data usage is large, generally most of these mobile users spend 80% of their time indoors and other being outdoors [31] which gives explanation as to what architectures might be needed [19].

The three criteria's for 5G standardization are data rate, latency, and energy costs.

The three cases for the data rate are area capacity, edge rate and the peak rate. The universal agreement for area capacity is expected to be a thousand times from 4G to 5G [1] [12] by the year 2020 [12]. Area capacity is defined as the amount of data that the network can provide to its users (bits/s per unit area). Secondly, edge rate is the minimum data rate that a user can obtain from the network. The 5G approximation numbers for edge rate are five percent that is between the ranges of 100Mbps to 1Gbps whereas the fourth generation standard edge rate is around 1 Mbps at five percent [1]. Lastly the peak rate is the maximum number of data rate that a user can receive from the network which is generally known to be a marketing tool [1]. To achieve a data rate of a thousand times for 5G it would require a combination of three technologies. The first one would be mmWave spectrum which would allow a rise in bandwidth needs [1]. Secondly the improvement in the spectral efficiency for MIMO would allow each node to have an increase in bits/s/Hz [1]. Lastly to maximize the spectral efficiency it would need multiple active nodes that can be placed a unit area known as densification and offloading [1]. To merge these three requirements, small cells has been proposed in the industry to solve these problems.

As for latency it is expected that 5G round trip latencies will be at around 1ms as this is required for resource sharing and access, whereas 4G is at 15ms [1]. It is essential to have low latency numbers for applications such as virtual reality (wearable devices being google glass) [1], driverless cars, tactile internet [13], health care, smart grid, and transportation. Tactile internet involves devices that have software applications that require a screen to be activated by touch.

Furthermore, energy and cost for 5G must be reduced as the increasing infrastructure to meet the 5G requirements is large based on the comparison from 4G to 5G. The cost of infrastructure for mobile and base station will be decreased due to the available and affordable CMOS technology that can be utilized for mmWave frequency bands in transmitting and receiving antennas [12]. Additionally this 5G technology requires multiple base stations for urban areas which will also reduce the cost and provide wireless backhaul that allows for easy administration of maintenance cost [12]. As currently the energy cost to run the current wireless network is 70% for mobile operators [13] which causes the service to be increased in price for the end user. A reduction in energy cost will help to make 5G feasible to the end user and reduce pollution into the environment. Some techniques on energy efficiency for base stations can be done by switching cell sizes based on traffic load [25], smart sleeping modes and idle logic [17].

To solve these standardization issues, it would involve a combination of MIMO, mmWave, and small cell techniques. Lastly base stations made for the 5G standardization at different cell locations must still be able to service older technology usage being 3G, 4G, and Long term technology advanced [12] for transitioning users to 5G.

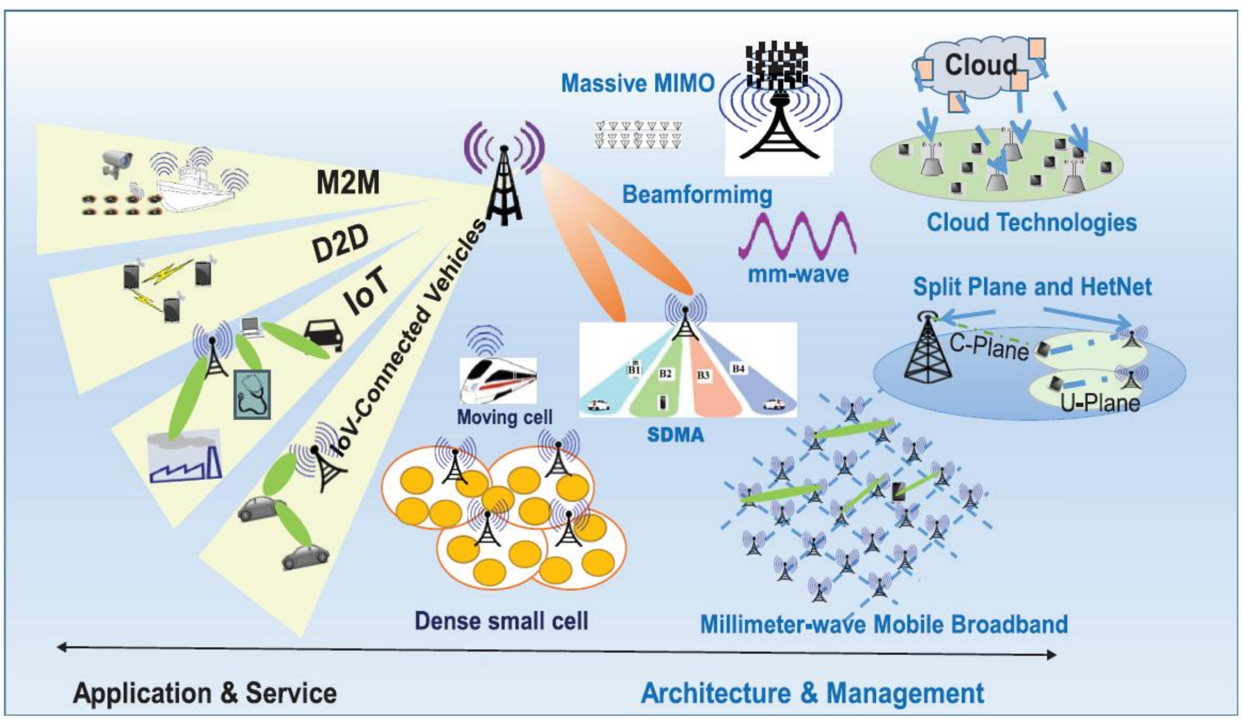


Figure 1 A snapshot of development for 5G Cellular networks [17]

To provide 5G the high data rate capacity, mmWave frequency bands will be used. MmWave frequency bands falls under the 3 – 300 GHz range. A pictorial view of the mmWave spectrum is shown in figure 2.This frequency spectrum currently has not been fully utilized by the industry as wireless communication at the frequency spectrum of 57-64 GHz and 164-200 GHz are still not applicable [17]. Despite some of these spectrums that are not useable, it still provides a large data rate than the current system [17] [28] which figure 2 shows the scope of the frequency spectrum and figure 3 shows its availability. The current wireless applications that have been using mmWave bands for the past decades are military applications, radio astronomy, radar, and airport communications[17].Furthermore frequency spectrum assigned by the federal communication commission at the 59-64 GHz are considered to be unlicensed wireless communication[17][28].

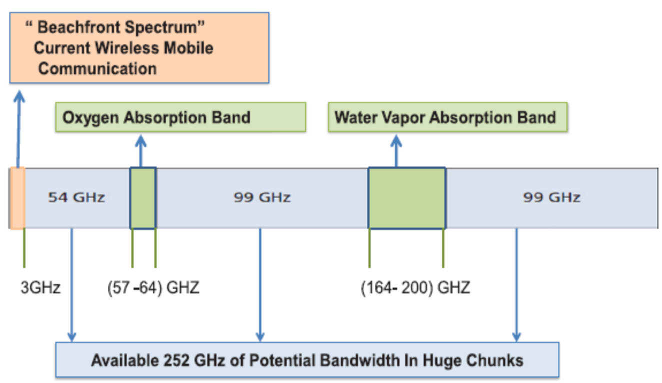


Figure 2 mmWave spectrums [17]

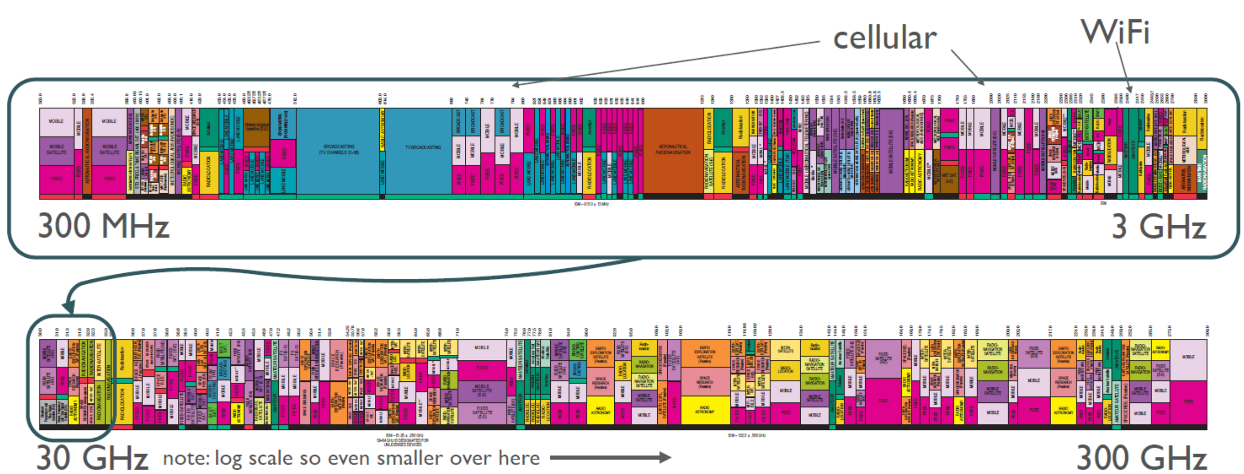


Figure 3 Usage of current Wireless communication on mmWave [29] [30]

Some Industry perspectives to 5G

Ericsson approach to 5G is allowing its 4G LTE network devices to be supportable on the 5G network so that traditional carrier frequencies can still be used [17]. Ericsson will be unveiling its 5G technology at the 2018 winter Olympics in partnership with SK Telecom [17]. Qualcomm intentions is making 4G and 5G to work in parallel that would provide a high quality of services, novel services, cost and energy reduction[17]. Huawei's perspective to 5G is finding vital 5G advances by cooperating with partner such being universities, international trade associations, and governments[17]. Nokia's standpoint to 5G is enhancing spectrum usage through heterogeneous deployment and exploration in the tactile internet and augmented reality [17]. Lastly Samsung electronics visualization for 5G is to provide its users high quality multimedia content, and the internet of things with a concentration in cloud computing [17].

MmWave

The premier spectral band currently used for 4G and LTE carriers spanning in the range of hundreds of MHz to a few GHz which are in the centimeter to meter wavelengths. This spectrum has become nearly completely saturated in peak usage cases [1]. This spectrum, called 'beachfront spectrum', cannot be incrementally improved much more and an exponential density increase in users is projected. Densification and offloading are insufficient practices; more bandwidth is absolutely necessary. Ideal spectrums in the ranges of 30 GHz -300 GHz and 20-30 GHz are ideal candidates for a 5G carrier.

These frequencies pose challenges that, until recently, could not be tackled. Primarily, propagation loss/ pathloss are much larger, atmospheric degradation, low diffraction around obstacles and weak object penetration [1]. Equipment costs and phase noise of high RF circuitry also posed a signal quality problem.

As frequencies increase, antenna size shrinks reducing the effective aperture of the antenna shrinks also thus growing the free space pathloss between the transmitter and receiver. Effective aperture of an antenna, relates to the amount of power that is captured from an incoming plane wave and is described by the equation:

$$A_e = \frac{\lambda^2}{4\pi} G$$

As general rules of thumb an order of magnitude increase in frequency adds 20dB power loss [1]. If the aperture at one end of the link is held constant with rising frequencies, the free space pathloss remains unchanged.

Impenetrable objects with 'knife edge' quality can diffract radio waves by Huygen's Principle as in figure 4, but this effect weakens as frequencies increase [2]. Even sharp corners at mmWave frequencies cannot diffract enough of the wave to cover 'shaded' areas like current technologies [1].

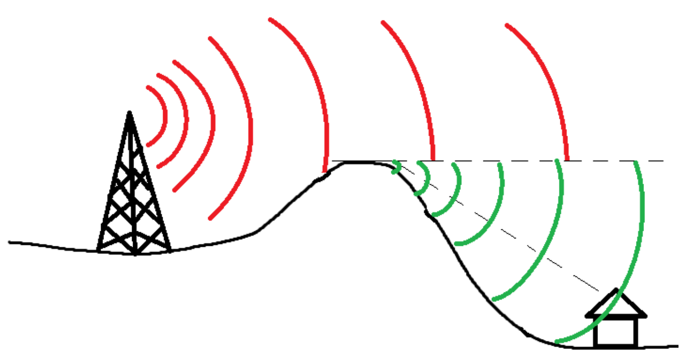


Figure 4 Radio diffraction

Specular only propagation means blockages for non-LoS (Line of Sight) receivers. Up to an additional 40dB/decade of loss is expected due to blocking over the aforementioned pathloss estimates; blocking is a first order effect. For the expected small cell base station spacing of 200m, atmospheric and rain absorption does not play a significant contribution to the losses [3].

Large array antennas are the best solution for pathloss problems if the beams are steered effectively. It is estimated that antenna sizes will be 10 to 30 times smaller than current 2.5GHz system for mmWave so multi array systems can be made without using more area than current configurations [9]. Narrow beams are highly direction and change many wireless system parameters and traditional design steps [1]. Beam interference is not the limiting factor in 5G as in 4G, instead channel noise limitation is. In addition to antenna arrays, phantom cells or soft cells [4] are proposed solutions to handle payload data transmission through small-cell base stations whereas infrequent control signals could be held in microwave frequencies of macro-cells [5]. This will provide a stronger connection when transitioning between small cells and mitigating problems in high mobility devices.

Signaling Systems

The transition between cellular generations has been marked with a fundamentally novel signaling technique that is able to handle larger number of connections and provide better quality of service. From analog FDMA (1G), digital TDMA (2G) to CDMA (3G) and OFDM (4G), signaling systems have drastically changed refreshing the hardware/software relationship. For 5G systems, it seems as if the signaling system will likely remain fundamentally based on the OFDM (downlink) signalling of 4G and LTE systems [1]. OFDM (Orthogonal Frequency Division Multiplexing) builds upon TDMA and FDMA concepts using orthogonal subcarriers that are dynamically scheduled in time and shifted in frequency based on channel properties. Data is transmitted through fixed sized ‘resource blocks’ in large frames within which resource allocation is dynamic [6]. These blocks can be digitally filtered and time-frequency resource slot allocation can address interference problems. Earlier challenges of frequency offset correction and synchronization have been solved [1]. OFDM implementation involves computationally efficient FFT/IFFT blocks and will also work seamlessly with MIMO [1].

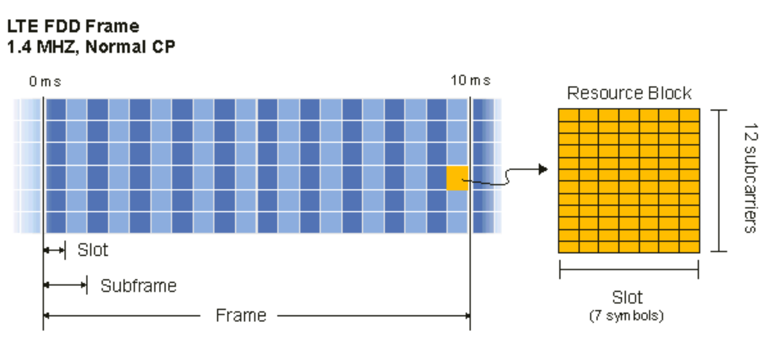


Figure 5 LTE Frame Structure [7]

LTE OFDM frame has a maximum size of 100 Resource blocks which equates to 20MHz or 1201 subcarriers. In time domain, a frame is of 10ms length containing 10 subframes of 1ms each. Subframes can either be in uplink or downlink mode transmitted simultaneously on separate subcarriers in FDD

(Frequency duplex division) mode or on separate timeslots over the same subcarriers in TDD mode (Time duplex division) [7]. While downlink signals are of type OFDMA, uplink signals are instead SC-FDMA. This is because SC-FDMA has lower peak to average power ratio, improving power consumption on the user's cellular device.

During uplink; user data in serial form, is first modulated in time domain by QPSK, 16QAM or 64QAM, then the time domain symbols are transformed into the frequency domain representation using an M-point FFT block and placed into an OFDM symbol of length N [7]. Here M is usually less than N since users are usually not allocated the entire symbol space. The downlink process is similar but the data is scrambled, modulated and parallel mapped into the user allocated symbol space right away.

Migrating OFDM to the 5G system poses some serious challenges. Peak-to-average-power ratio (PAPR), in OFDM signaling is higher than other formats which is the primary downside to this signaling system. The spectral efficiency can also be saturated further if orthogonality requirement of the signals was relaxed. Alternatively, cyclic prefix guard symbols that deal with intrasymbol interference can be made fewer in number. It is difficult to design a power amplifier in the high frequency mmWave range. Some improvements can be made by modifying OFDM for 5G:

- Time frequency packing
- Filterbank multicarrier (Universal filtered multicarrier)
- Generalized Frequency Division Multiplexing
- Single Carrier
- Tunable OFDM

Tunable OFDM seems to be the most viable, all-encompassing solution, to current OFDM limitations. In this technique, the software defined nature of radio is exploited such that frame and physical-layer properties are dynamically modified such that acceptable quality is achieved without wasting power or information space [1]. For example, cyclic prefix (CP) length can be modified based on changing channel response. FFT block size can be modified based on user allocated space and network crowding.

After the fundamental of signaling are firmly established, it is predicted that future implementations of 5G networks will become virtualized. Network function virtualization, take traditionally hardware aspects of communication links and runs them into virtual cloud computing infrastructure [1].

Channel models

There are several accurate channel models for mmWave transmission that are currently in use for simulation of outdoor experimental work. These channel models are comprised of research conducted in real world testing at 30GHz taking into consideration: rain attenuation, foliage attenuation, multipath spreading, AOA and reflection coefficient of materials [8]. Firstly, it is expected that highly directional steerable antennas will be commonly used to incorporate SDMA. This will improve density in heterogeneous networks and reduce intercell interference; providing further evidence that mmWave systems will be noise limited.

Figure 6 shows the results of 38GHz mmWave testing on University of Texas campus from [8] where path loss exponents were determined using steerable TX and RX antennas. Here the 25dBi narrow beam antenna had larger path loss than the narrow beam 13.3 dBi antenna. It was determined that often Non Line of Sight (NLOS) signals would be received for different TX/RX combinations where the multipath signals were 10-20dB weaker than the strongest received signal. In general, NLOS links were 10 – 50 dB weaker than their LOS/obstructed-LOS counter parts. Scattering was predominantly found on ground based receivers where object clutter was abundant. Data suggested that mmWave base station transmitters need not be more steerable than a 60° span (with TX at two story elevation) in urban environments. Furthermore, site specific planning using ray tracing is recommended pre-deployment to address niche environmental factors.

	25 dBi RX Ant.		13.3 dBi RX Ant.	
	LOS	NLOS	LOS	NLOS
Path Loss Exponent n	2.20 (clear 1.92)	3.88 (best 3.13)	2.21 (clear 1.90)	3.18 (best 2.56)
Path Loss σ (dB)	10.3 (clear 5.1)	14.6 (best 10.7)	9.4 (clear 3.5)	11.0 (best 8.4)

Figure 6 Path loss exponents and standard deviation (38 GHz) [8]

The study also determined a log-normal shadowing model given by the close-in free space model:

$$PL(d) = PL(d_0) + 10n * \log(d) + X_\sigma$$

Where d_0 is the 5m reference distance, X_σ is the shadowing Gaussian random variable with 0 mean and σ standard deviation, and n is the path loss exponent.

Antenna elevation can boost range of the cell to 300m, but that value is strongly affected by X_σ. It is suggested that microcell deployments of cell radii less than 200m should be used. Figure 7 plots omnidirectional path loss for 28 GHz and 73 GHz testing in New York City for both LOS and NLOS links from [9] using unity gain antennas.

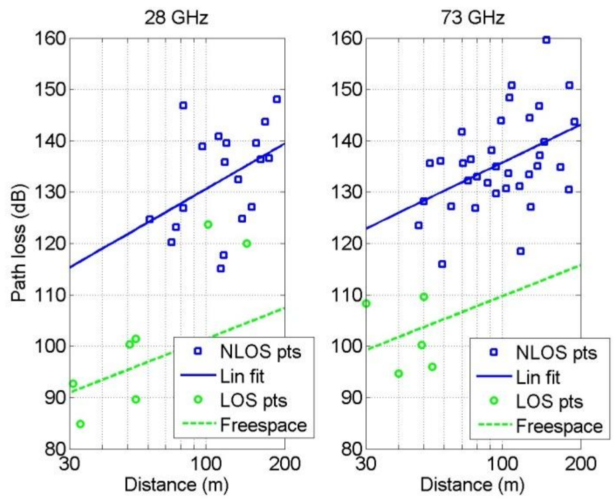


Figure 7 Path Loss in NYC testing from [9]

The time spreading due to multipath effects were captured in AoA (Angle of Arrival) power profile measurements in [9]. These measurements indicated three distinct lobes/angular clusters for one specific beam link. Poisson random variables can model these cluster approximations. The shape indicated that local scattering occurs at both the TX and RX ends. Cluster power distribution is described by:

$$\gamma_k = \frac{\gamma'_k}{\sum_{j=1}^{K} \gamma'_j}, \qquad where\ \gamma'_k = U_k^{a-1} 10^{-0.1 Z_k} \quad a = r_\tau$$

For K number of clusters, of random γ variable with Uniform random distribution. Z_k is a Gaussian log normal random variable due to shadowing effects.

It was found that large portions of signal energy are located in the secondary and tertiary lobes indicating the reflective nature of mmWave. This Doppler spread is mitigated by directional antenna arrays. SINR data showed mmWave systems could contain greater than 1 Gbps capacity with 5% edge rates of greater than 10 Mbps [9]. For simplicity, we will

MIMO

There are two types of MIMO, single user MIMO (SU-MIMO) and the multiuser MIMO (MU-MIMO). SU-MIMO involves a certain number of antennas that can provide service to a mobile device where it uses time division to differentiate data being sent from the base station to other mobile devices in the area. As for MU-MIMO it operates by its antennas being able to transmit data to all the devices at the same time that is parallel without interruption using beamforming techniques [14], [1].

For MIMO to work with mmWave there are two unique options; spatial multiplexing or beamforming, or a combination of the two. Spatial multiplexing operates by splitting its signal into multiple streams for parallel transmission to be sent to the receiver. Each stream undergoes different propagation paths to reach the receiver which has a selective time delay to create frequencies that allows the receiver to reconstruct the signal using the same RF channel [14].

There are two types of spatial multiplexing. The open loop version of spatial multiplexing being time division duplex single frequency systems which relies on the transmitter to estimate the channel state information to transmit to the receiver, and the receiver does not provide channel state information [14]. As for the closed loop version, the signal being transmitted relies on the channel state information to maximize the best transmission to the receiver, and then the receiver sends back channel state information back to the transmitter [14]. Channel state information provides information in regards to scattering, noise, fading, and the power decay involving distance [18]. Spatial multiplexing is used for increasing data capacity for the user due to its multiple pieces. It thrives in a high SNR environment with limited bandwidth but consumes a lot of power to operate [14]. The disadvantage of spatial multiplexing operating in a low SNR environment is that its bit error increases as the power used to split the streams is not even when it arrives at the receiver [14]. Additionally, this also creates a cut-off for its data capacity to the user [14].

Beam forming uses amplitude and phase modulation to transmit a directed beam pattern from its transmitter and receiver. The benefit of beamforming is that it reduces the propagation path loss by its multiple beams being directed to the receiver to maximize the signal strength [14]. Additionally, this also provides an increase in the signal to noise ratio [14]. The other benefits are a "reduced co-channel interference due to spatial selectivity of directional antennas" [14]. Furthermore, beam forming in combination with mmWave is suitable as its directed adaptive antenna can be manoeuvred to take advantage of the objects reflection and scattering for transmission to maximize signal strength which allows the receiving signal to have the same frequency and phase for coherency [14]. As for beam forming there are three types of architecture which involves analog, digital and the hybrid that takes into account of spatial multiplexing and beamforming.

Analog beam forming has low power consumption for operation as it has one RF chain for every one antenna. Digital beam forming has the most flexibility but has a disadvantage in power operation and cost especially for mmWave large bandwidth and number of antennas that are needed to be involved. Its power consumption comes from its large number of RF chains, bandwidth and antenna requirements [14].

The hybrid architecture takes advantage of the analog's beamforming architecture to achieve a moderate power consumption and operation for a long range transmission for a radius of 200m [14]. As for the short range transmission for the hybrid architecture it utilizes spatial multiplexing. The hybrid architecture is suitable for mmWave as spatial multiplexing (open loop and closed loop) is already used for older network standards being "4G LTE, LTE-A, and IEEE802.16e/m" [14].

As for beam forming operating with mmWave there is no limit to its bandwidth that is based on its power operation [14]. As bandwidth increases, its SNR also increases for beam forming [14]. Although beam forming has an issue with SNR, it has no issue with co-channel interference as it is minimized by its angle diversity [14]. Beam forming is suitable for communication ranges of 100m-200m as it is able to consume power that is below one watt power level in the case of LOS (line of sight) for propagation path loss [14]. For NLOS, the hybrid architecture of spatial multiplexing and beam forming would be used in the scenario of high propagation path loss for "capacity gains" [14].

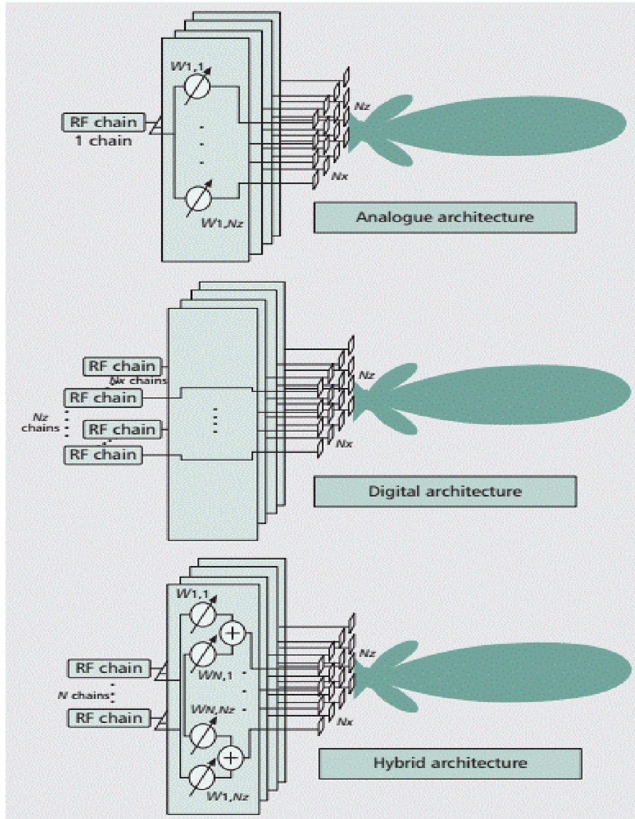


Figure 8 Three types of beamforming architectures [14]

To make beams to be narrow for beam form technology it utilizes beam forming weights. The beam weights are derived from the channel state information of the channel. The two proposed beam forming weights by Rappaport's research group for mmWave are:

1) Codebook based beam forming
2) Beam Forming weight optimization based on Angle of departure(AoD) estimation

Codebook based beam forming uses a set of phase weights per antenna element to make a codebook entry. Combining the multiple codebook entries creates a codebook, as the codebook increases in size it allows for fine tuning of the antenna beam [14]. This being that the base station and mobile station will search through the code book to find the best connection for transmitting and receiving data [14]. There are different types of codebooks created for the base stations and mobile stations due to the number of antenna used and form factor [14]. This method of beam forming weights is too costly for consumer products that require fine tuning of phase resolution [14]. The second method being AoD estimation utilizes compressive sensing technique to estimate the spatial features of the mmWave channel. Compressive sensing does this estimation by using the signals compressibility or sparseness that would be used to receive a signal for reconstruction [14]. This method of beam weights is more superior than the codebook method as its code book is a fraction of the size, which would lead to less cost for hardware parts [14].

Small Cell

Originally small cells (femtocell base stations) were used to solve small coverage area that macro cells were not able to cover but now for 5G network it purpose is used to increase data capacity for the network [18]. These femtocell base stations are commonly used in residential areas and are designed to be low maintenance [18]. Its low maintenance (self-install by the end user) cost for small cells makes it attractable for large scale deployment and also its low power consumption [18]. The cause of low power consumption for small cells is due to their close proximity to the end user [18].This low power consumption will be useful for the mass deployment of small cells for 5G. Most of these small cell base stations that are used today for residential use are composed of 96% femtocell base stations [18] [27]. Its backhaul connection comes from the user's wired broadband or fiber connection as shown in figure 9 [18].These small cells provide high quality of service for its dedicated area, and energy efficiency than its previous counterpart being macro cells [18].

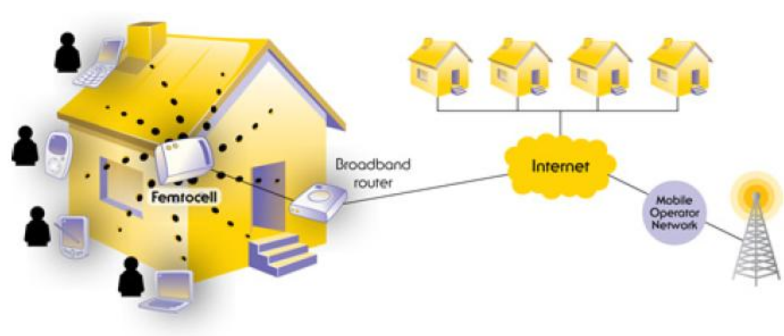


Figure 9 Femtocell base station for a residential area [18].

Presently small cell base stations use single manoeuvrable Omni-directional antennas [26] due to their cost and form factor constraints for residential use [18]. Improving the spectral efficiency helps to increase the data rate output for small cell base stations [18]. In order to improve the spectral efficiency of small base stations, advanced antenna techniques are to be used. These advance antenna techniques fall under MIMO technology that is spatial multiplexing and beam forming. These advance techniques are commonly used in today's wireless standards for this being IEEE 802.11n, IEEE 802.16, Wi-Fi, WiMAX, LTE, and LTE-A [18]. This component will also help to make it easier to integrate for the 5G cellular network.

For small cells to work with mmWave that are nested, cells will have to cover a small area attributed to picocells (which covers a radius of 100m) and femtocells (which covers an even smaller area similar to WIFI) [1]. According to the article [1] it states that the signal to interference ratio will not change when the cell size has shrunk [1]. The base station in any cell size will be able to provide services to an individual user or some users that involves the backhaul connection and its resources [1]. The more small cells that are available to the end user, the backhaul problem and providing resources will no longer be an issue as each base station serves a small number of end users [1]. Nested small cell provides benefits of reusing the same frequency spectrum and as well as reducing the load from end users for base station resources [1]. Although small cell provides these benefits, it has a rising infrastructure costs for multiple small cells required. There is still a mobility issue between small cells that needs to be developed for the edge rate that involves a heterogeneous network [1]. The disadvantage of multiple cells (small, micro, pico and femto cells) is the high co-channel interference due to the densification of connected nodes together [17]. To solve this issue, traditional omnidirectional antennas presently used today would need to be replaced by compartmentalized directional antennas [17] that uses beamforming technology with SDMA (space division multiple access). SDMA allows frequency reuse for beam forming antennas at the receiver and the transmitter [17] [24].

The design of 5G network antennas will be crucial as smart antennas with SDMA will be required to solve the high co-channel interference, and to also have efficient power usage for its coverage area [17].

Benefits of SDMA

SDMA is useful for small cell deployment and NLOS as it helps to mitigate issues involving co-channel and multipath interference [17].In order to use SDMA with an adaptive antenna it requires beam forming training to obtain the weights to get the desired spatial beam patterns [17]. The spatial beam pattern coming from the base station is able to differentiate and locate the device when communicating with other devices simultaneously [41]. For SDMA to work with the base stations it must be able to concurrently transmit and receive multiple spatial beams in desired directions for each device[17][22]. These desired spatial beams depend highly on the feedback methods and computation of the channel state information along with the beam forming vectors [17]. Currently SDMA is still a novel multiplexing technique that still requires further research for it to work with a massive number of antennas and a small number of RF chains [17]. The smaller the number of RF chains, the lower its power consumption and the multiple antennas helps it to communicate with multiple devices using the concept of MIMO. Figure 10 below shows an illustration as to how SDMA operates.

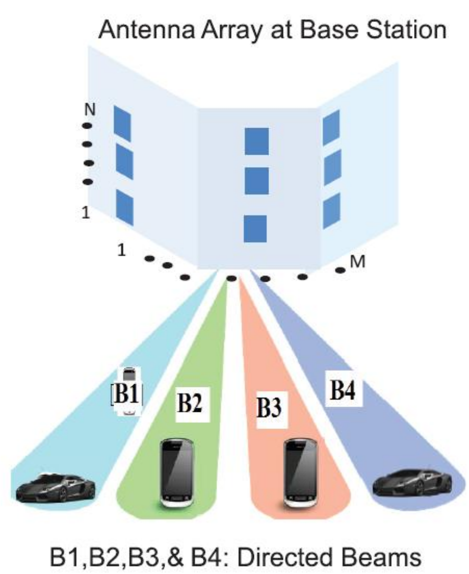


Figure 10 Spatial Division Multiple Access [17]

Smart Antenna configuration

Smart antennas will play an essential role to 5G as it use for multiple beams and SDMA capabilities would help to diminish the interference issues in the coverage area, and to provide efficient power usage involving the mobile stations and base stations [17].Additionally at the same form factor of the aperture size its narrow beams produced for transmission will be able to increase the amount of energy at higher frequencies [17] [33]. Furthermore, smart antennas also allow the use of the same channel to be used by different narrow beams which solves the co-channel interference [17] [32].

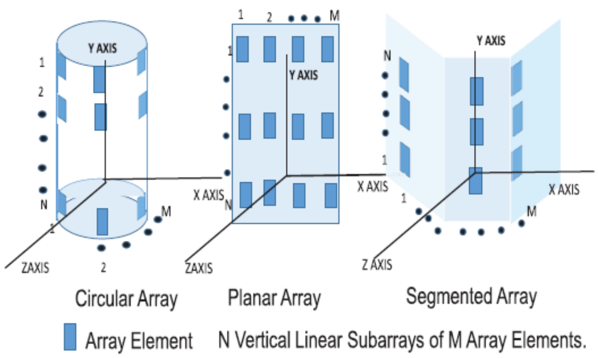


Figure 11 Smart antenna arrays

There are three promising array configurations for smart antenna as seen in figure 11. The circular array allows for a wide scan range for beam steering but lacks in directivity [17]. The planar array provides good directivity for a beam, but has deficiencies in the wide scan range [17] [34]. A combination of the two array configurations forms a segmented array that allows the antenna to have directivity and wide scan range [17] [34].

A change in the Wireless Architecture for 5G

The traditional macro hexagonal coverage can no longer be used as it is not able to support the high data rate and restrained millisecond latency requirements [17]. The wireless network model has changed from a base station centric network to user centric network as seen in figure 12. The user in the user centric network is also expected to be involved in the storage, delivering content and to perform processing for the network [17]. This network model has changed as it has been fueled by the wireless industry demand for smaller cell deployments [17].

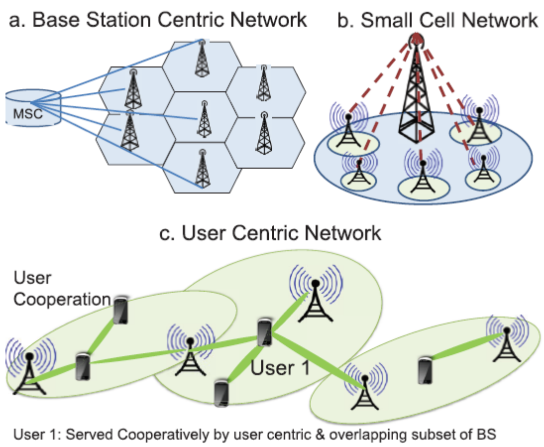


Figure 12 Changes in network architecture [17]

2 common types of 5G networks

Currently the 5G network that has been developed by Samsung Electronics has two types of possible topologies where mmWave is integrated with 4G infrastructure as shown in figure 13 and the other is a grid form mmWave Small cell network in figure 14.

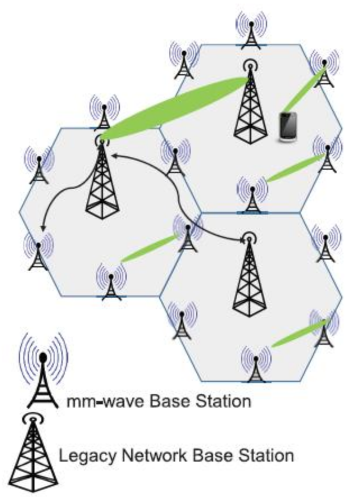


Figure 13 mmWave with 4G network [17]

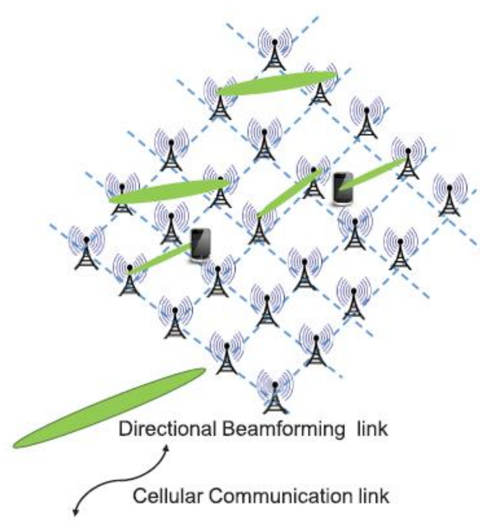


Figure 14 mmWave Small Cell networks [17]

The mmWave with 4G network is a hybrid system where it allows users to switch between the two networks for better quality of service [21] or mmWave is used strictly for data communication and the 4G network as the control system for information [17][21]. As in the case of mmWave grid small cell, it only utilized the mmWave technology [21] for wireless access links and the backhaul connection [17]. Since narrow beam for mmWave provides satisfactory spectrum overlap, this expands the large number of end user to be serviced and link quality between base stations in the grid [17] [23].

A Heterogeneous network

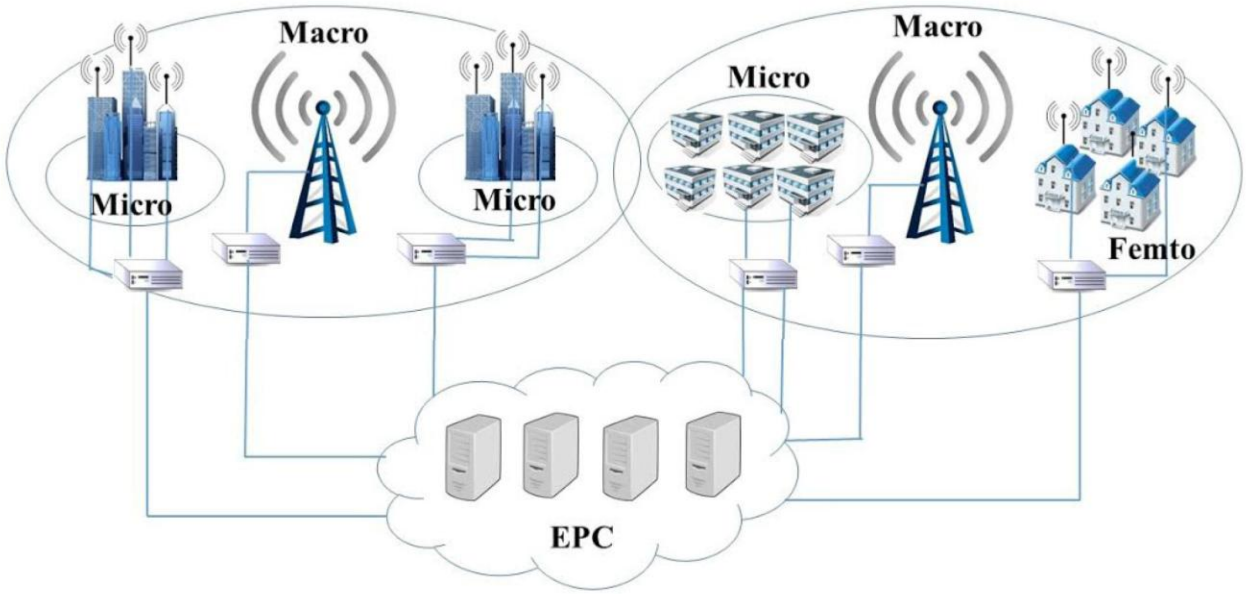


Figure 15 Heterogeneous architecture [17]

A heterogeneous densification network involves a massive deployment of small cells to work alongside with macrocells. This network architecture allows an increased in network capacity and supports coverage holes where coverage needs to be extended [17] [35] [36]. The heterogeneous network is composed of existing macro-cells that overlaps with small, micro, Pico, and femto cells that allows for frequency reuse [13][37]. Figure 15 shows the cooperation between macro cells and small cells. To resolve the issues of interference between the macro cells and second tier cells, reverse time division duplex mode is used [38]. In the reverse time division duplex mode the small cell access operates as a downlink when the base stations functions as an uplink and opposite happens when roles are reversed [17].Currently the authors in [17] [39] suggest that companies such as Samsung mobile solutions and Qualcomm technologies Inc. are focused on interference management methods for the device and the network. This is essential on devices perspective as it maximizes the received interference signals structure [17] [39].The inference signal structure involves coding schemes, channel, modulation constellations and resource allocations [17]. Radio access technology provides handover decisions this being multiple RATs have provided an increase in capacity and connectivity for the network [17]. The role that multiple RATs will play in the 5G network is that it will not replace the existing network's but will improve and integrate with it[13]. Massive MIMO and mmWave will play an essential role to heterogeneous networks as mmWave have very small wavelengths which allows a large number of antenna elements to be placed in a small form factor which make it possible for massive MIMO at the receiver and transmitter [13]. It is proposed in [13] that mmWave frequencies are to be used for outdoor communication for connections that involved the backhaul links and also for the indoor use wireless applications. The backhaul issues for heterogeneous network can also be solved by cloud based platforms that would help provide smooth connectivity between locations and handoffs between the massive deployment of small cells [17] [40].

A possible heterogeneous architecture is proposed [13] and is shown in figure 16. This architecture relies on microwaves and mmWave bands. Microwave frequencies are used for outdoor communication that requires long range due to path loss increases as the carrier frequency increases [13].The uses for mmWave frequencies are short range, high data rate communication for indoors, backhaul links, and line of sight communication [13]. The cause of mmWave frequencies short range is due to the attenuation loss at the different frequency bands. The role massive MIMO would serve in this network would be the transportation industry for fast moving objects being buses and trains that would utilize the microwave band [13].

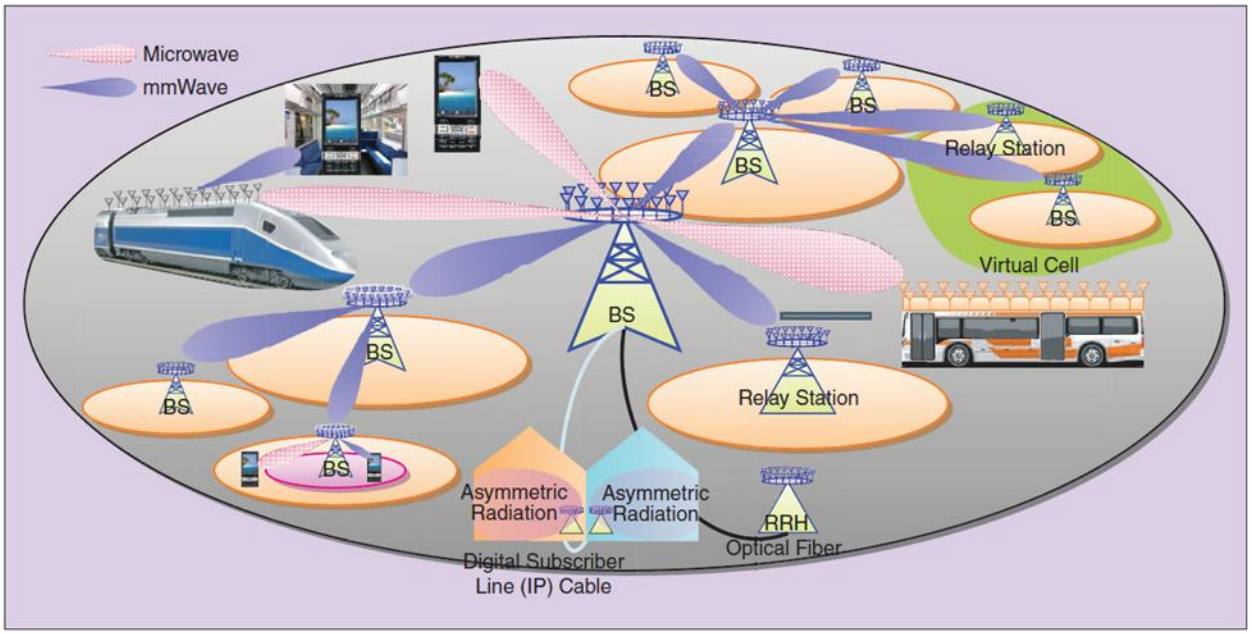
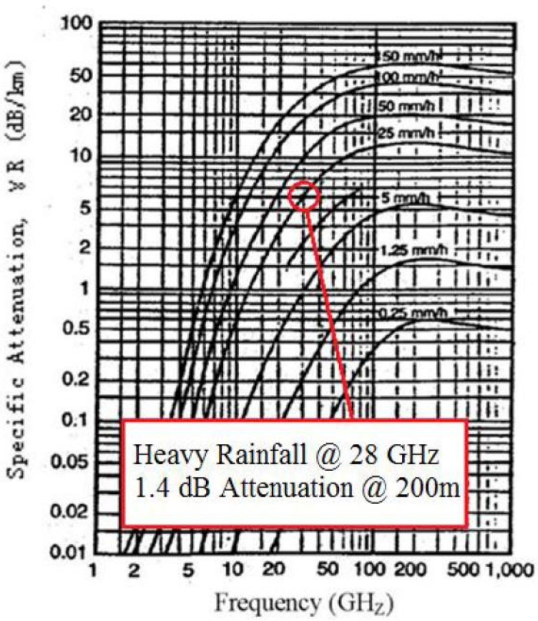


Figure 16 Heterogeneous network integrating mmWave and massive MIMO [13]

While the heterogeneous network services for 5G it still services the older mobile station that involves 3G, 4G and LTE-A [10]. As for the backhaul connection it can be solved by using a mixture of cable and wireless. It is found that mmWave at the 28 to 32 GHz spectrum for small cells have slight effect for its cellular propagation when it experiences rain attenuation for a distance under 1km [12]. This slight effect for its cellular propagation has been confirmed by many other researchers in the field [12] [15]. In the scenario for heavy rain conditions (1 inch/hr) the attenuation is 7dB/km at 28 GHz as mentioned [12] to have attenuation of 1.4 dB for a distance of 200m. Additionally for atmospheric absorption it has a slight effect for propagation path loss for 200m as seen in the figure 17 below for 28 to 38 GHz [12]. The authors in [12] claim that urban environments use small cell sizes at the order of 200m, therefore mmWave technology can still be used to solve 5G's requirements. Overall, the mmWave band for 5G plans to take advantage of the unused frequency where the bands of interest are 20-90GHz, and 70-80GHz [18]. Although these mmWave bands are subjected issues of rain attenuation, high atmospheric attenuation and high path loss, a combination of small cells combined with mmWave with a coverage area of 200m will have little effect on the wireless communication.



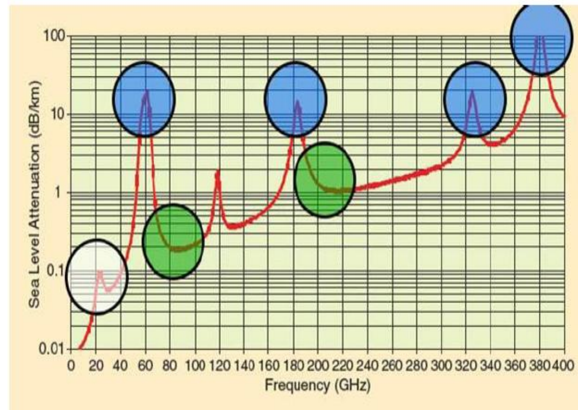


Figure 17 [12]. Atmospheric absorption across mm-wave frequencies in dB/km [16]. The attenuation caused by atmospheric absorption is 0.012 dB over 200 m at 28 GHz and 0.016 dB over 200 m at 38 GHz. Frequencies from 70 to 100 GHz and 125 to 160 GHz also have small loss.

Figure 18 Rain Attenuation for mmWave [12]

Conclusion

The research and development direction of 5G's requirements will conclude to using the heterogeneous network. The heterogeneous network provides the bridge for consumers that utilize mobile devices for the old cellular network and mobile devices for the new cellular network. In order for this heterogeneous network to operate for 5G it will rely on the following technologies that are mmWave, small cell, MIMO, and smart antennas used with SDMA. The heterogeneous network provides savings for the mobile operators as it retains the old mobile users to be serviced and the new mobile users that use 5G applications can be serviced by the small cell's base stations that use mmWave.

Simulation

For the purposes of simulation, we are trying to learn about the channel characteristics of mmWave 5G. We would like to see the effect of channel parameters that are estimated in [8] and [9] on the quality of received signal. In order to accomplish this, we will attempt to create parts of the proposed 5G system downlink by modifying current 4G/LTE links. We will also incorporate elements of [10] and [11] to generate a simple OFDM signal. For simplicity we will omit the MIMO configuration and the LTE frame structure as the focus of the simulation is signal quality. We hope to be able to see the same relationships that were noted in the works of [7] and [8].

Table 1 shows some of the primary channel parameters that will define our simulation. We intend to operate at 28 GHz assuming variables derived from the dense NYC metropolis. Figure 19 shows the link block diagram for the proposed simulation; each of the blocks will be constructed using Simulink defined blocks or through MATLAB script functions. If necessary, MATLAB, and C programming will also be used for computation.

Table 1 Channel Parameters

Variable	**Model**	**Model Parameter Values (**28 GHz)
Omnidirectional path loss, *PL*	$PL = \alpha + 10\beta \log_{10}(d) + \xi$, d in meters	$\alpha = 72.0$, $\beta = 2.92$
Lognormal shadowing, ξ	$\xi \sim N(0,\sigma^2)$	$\sigma = 8.7$ dB
Number of clusters, K	$K \sim \max\{Poisson(\lambda), 1\}$	$\lambda = 1.8$
Cluster power fraction	See (3).	$r_\tau = 2.8$, $\zeta = 4.0$
BS cluster rms angular spread	σ is exponentially distributed, $E(\sigma) = \lambda^{-1}$	Horiz $\lambda^{-1} = 10.2^\circ$; Vert $\lambda^{-1} = 0^\circ$ (*)
UE rms angular spread	σ is exponentially distributed, $E(\sigma) = \lambda^{-1}$	Horiz $\lambda^{-1} = 15.5^\circ$; Vert $\lambda^{-1} = 6.0^\circ$

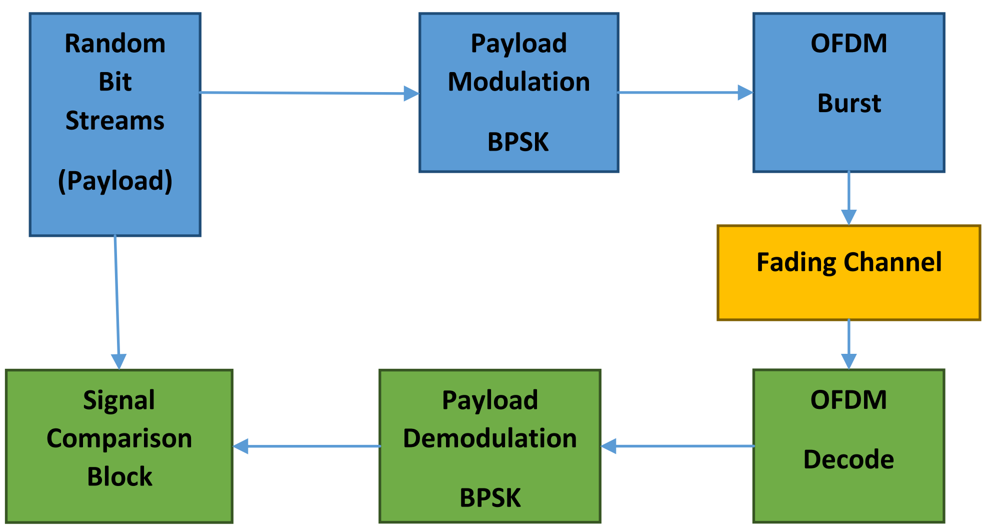


Figure 19 Proposed simulation block diagram.

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