WHITE PAPER

IN-BUILDING NETWORK EVOLUTION: FROM ***4G*** TO ***5G***

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1 INTRODUCTION

5G Networks, also known as 3GPP Release 16 (Phase 1) and Release 17 (Phase 2), promise to bring many technical innovations to the field of cellular technologies. The new networks will be able to provide a wide range of diverse applications, from asynchronous, low data rate applications targeting machine to machine communications (M2M) and the Internet of Things, to low latency very high data rate applications such as video gaming, and everything in between. 5G networks, unlike their predecessors, will be deployed over a wide range of frequency bands. Sub-6 GHz will be used for blanket, citywide coverage suitable for mobile coverage, while millimeter wave frequencies (24 GHz and above) are suitable for stationary point to multipoint high bandwidth coverage targeting residential areas. In this paper, we focus on key 5G features and discuss which type of 4G networks may be most affected by transitioning to 5G.

2 KEY 5G FEATURES FOR IN-BUILDING NETWORKS

2.1 BEAMFORMING

Beamforming is a technique that shapes the antenna array pattern in the preferred direction. This is done to direct antenna pattern in the direction of the serving customer (also called beam steering), and to minimize the pattern in the direction of customers that may jam the signal, which is also called null placement. Beam steering improves signal coverage, while null placement reduces interference. The overall result is improved Signal to Interference and Noise ratio, which increases signal throughput and system capacity.

An antenna array consists of N antennas that are separated by a certain distance. In analog beamforming, the same signal is sent to each antenna branch, but an antenna-specific phase shift is applied before transmission. In this case, one amplifier is needed for the whole array, but N phase shifters must be deployed, one for each antenna. This is illustrated in Figure 1 [1]:

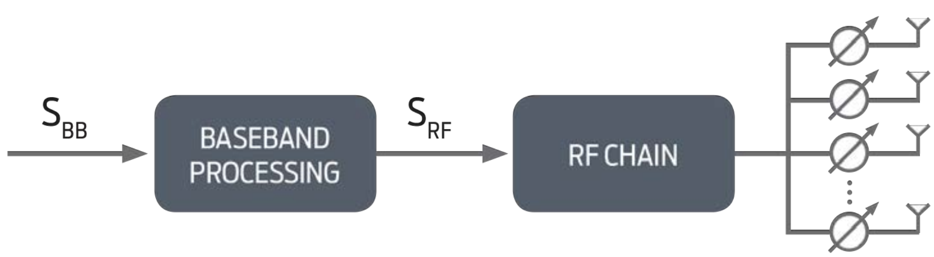

Figure 1: Analog Beamforming Architecture

Another option for beamforming is Digital Beamforming. This architecture is more complex because each antenna must have its own RF chain (upconverter and amplifier), while phase shifts are applied during baseband modulation. The architecture is shown in Figure 2 [1].

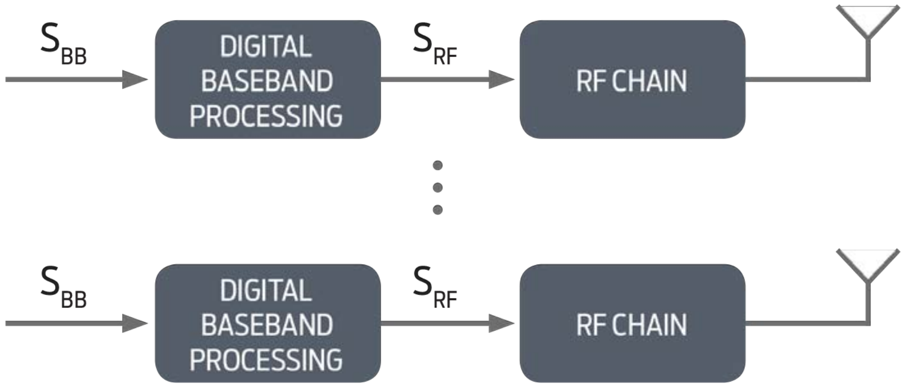

Figure 2: Digital Beamforming Architecture

A linear N antenna array produces a directional antenna with the maximum gain in one direction, and N-1 pattern nulls or “dips” at different directions [2]. If signal amplitude is the same for each antenna and only phase shifts differ, then either direction of the maximum gain or null pattern directions can be specified, but not both. If both amplitude and phase are specified at each antenna, then both the maximum gain direction and the pattern null direction can be specified. A technique called Adaptive Antenna Array calculates these amplitudes and phases (called antenna array coefficients) in real time, by minimizing the mean square error between the target signal levels for the serving user and N-1 interferes with the measured signal levels at these locations. The process of minimizing the mean square error yields the new coefficients, which are applied to the base station signal. The resulting signal is again measured at target locations by UEs and sent back to the base station. Then, the process of minimizing mean square error is repeated. The iterative nature of this process requires frequent signal measurements, which is essential for the mobile environment.

It should be noted that the underlying assumption is that the user and interferers have a significant spatial separation between them. This is an essential requirement because sufficient angular spread between the pattern nulls and the maximum gain must be maintained. An example of beamforming with a null in the direction of the interferer and maximum gain in the direction of the serving user is shown in Figure 3.

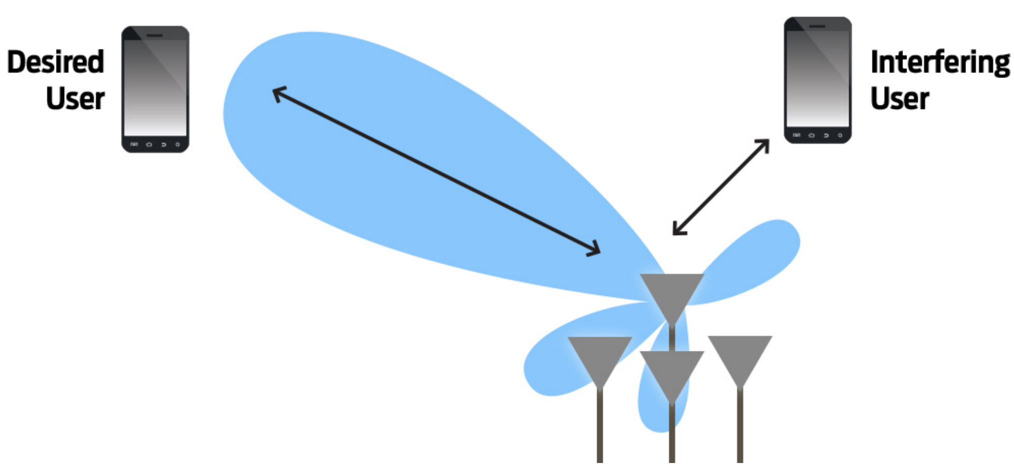

Figure 3: Example of beamforming with the maximum gain in the direction of the serving UE and the minimum in the direction of interfering (non-serving) UE.

2.2 MIMO, MU-MIMO, Massive MIMO

The original MIMO technology takes advantage of the antenna array to improve data rate by taking the original data, splitting it into equal parts and delivering them to antennas in the array. This process assures that each antenna transmits only a fraction of the original data. At the receiving end, another antenna array captures the fragmented data and reassembles it to its original form. If there are N antennas on both ends, the net result is that the data is sent and received N times faster than the data that would be sent using just one transmit and one receive antenna. This technique is known as Spatial Multiplexing Mode; it improves data throughput N times and works very well when Signal to Interference and Noise Ratio (SINR) is good, and both transmitting and receiving array have the same number of antennas. When SINR is poor, the original data is kept intact, and all antennas transmit the same signal. At the receiving end all antennas receive the same signal, but after combining, the received signal level is higher than what it would have been if only a single antenna is used at both ends. This method is called Diversity Mode and improves the signal coverage.

Multi-User MIMO is a technique when a MIMO signal is delivered to multiple concurrent users at the same time using the same frequency. The only stipulation is enough spatial separation so that only one serving UE is in the main radiation pattern beam. The question that is often asked is how many K concurrent UEs can be served by MXM MIMO antenna array? From antenna theory, we know that K ≤ M-1, but what do 4G and 5G standards suggest? In LTE-A, the number of concurrent users is limited to K=8, and while M must be greater than K, it is not a very large number. In 5G we have a more interesting case, a so-called "Massive MIMO", where both the number of antennas M and the number of concurrent users K are large. In the original "Massive MIMO" definition [3] it was also assumed that M>>K. However, the more general definition [4] only stipulates that M>K, while still allowing both to be large. Another paper gives a few examples of iterative computation of M and K under realistic energy efficiency assumptions [5]. The author comments that in case of strong inter-user interference when data rate per user is low, it makes sense to assign as many UEs as theoretically possible (M ~ K), to raise total throughput per base station. So, we see that while 5G requires both M and K to be large numbers, the actual ratio of M/K can vary quite a bit, and in some cases, it can be close to 1.

Massive MIMO is not only MU-MIMO with many more antennas, but also has new features that make it a significant upgrade over MU-MIMO. Amongst them is TDD only mode of operation which eliminates frequency selective fading that affects only one duplexing band, TDD or FDD, but not both. Using Massive MIMO on TDD only allows pilot signal used for channel estimate to be transmitted only on the uplink and takes advantage of channel reciprocity. Cell edge SINR increases with the number of antennas in the array, so naturally, Massive MIMO performs better in this region than MU-MIMO. [6]. Small-scale variation of propagation channel may reduce antenna gain. However, as small-scale variation is an independent variable, it can be shown that the probability that all antennas are affected by it quickly drops as the number of antennas in massive MIMO array increases [7]. Another way to describe this would be that the signal is 'averaged out' over antennas. This is also known as 'channel hardening' [8], and since Massive MIMO is expected to be deployed with many antennas at Base Station, channel hardening will result in negligible small-scale signal variation in time. Channel hardening allows for more predictable resource allocation, as the channel behavior itself is more stable than in MU-MIMO. An example of 5G Massive MIMO base station is shown in Figure 4.

Figure 4: 5G ready base station with 44 cross-polarized antennas in a panel

2.3 C-RAN NETWORKS

C-RAN is network topology that separates baseband processing and RF hardware and is technically not 5G standard. However, it will affect capacity planning for in-building networks, so it deserves mention here. C-RAN stands for Centralized RAN architecture that moves BaseBand Units (BBU) from Base Station housing to a centralized location, which is usually operators' Central Office. Doing so reduces operating costs because less power is required for cooling Base Station circuits. It also reduces the capital spent on real estate lease at the cell site, as less space is needed when BBUs are not present. The baseband signal is sent from the central location to Base Station via fiber link, where it is converted to RF, amplified and transmitted. Often, these Base Stations without BBUs are called Remote Radio Heads (RRH) as they contain only RF elements.

Back at the central office, BBUs are pooled among several base stations. Their traffic is monitored in real time, and BBUs are assigned and reassigned according to RRH traffic needs. This flexible resource scheduling reduces call blocking, as Base Stations do not have fixed number of BBUs; instead, they take BBUs from a pool of available BBUs. From Centralized RAN, networks may evolve to Cloud RAN, where routine processing of centralized BBUs is done by commercial, off the shelf servers located in the cloud. This cloud processing is called Network Function Virtualization (NFV). Cloud RAN might also mean that another service provider owns the baseband equipment. Both C-RAN architectures are shown in Figure 5

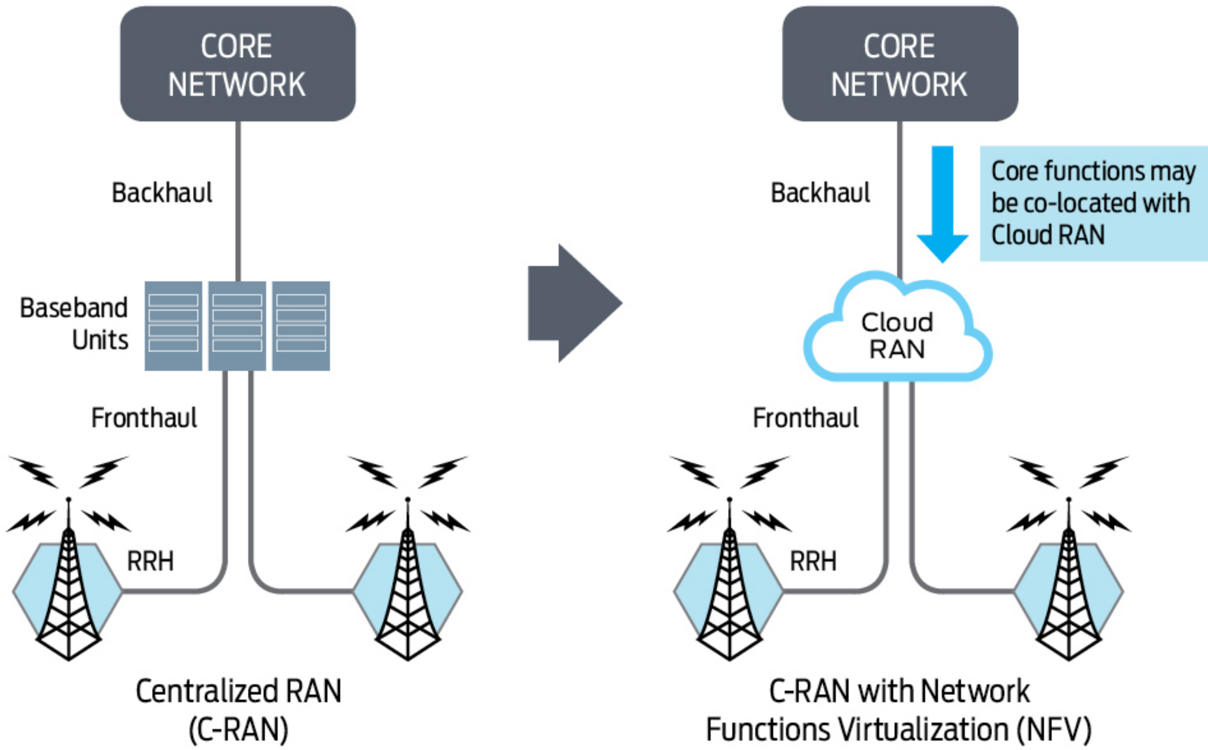

Figure 5: Centralized RAN and Cloud RAN

The impact on in-building design is at the capacity planning stage while calculating capacity requirements for Busy Hour. As BBUs are pooled, the in-building network is not likely to experience MAC Layer blocking due to an insufficient number of BBUs at any RRH. However, virtual BBU blocking may occur due to cloud processing limitations. Layer 1 blocking at an RRH is still a possibility, and this would occur when airtime utilization is projected to be greater than 100%, based on estimated capacity requirements at RRH.

3 5G IN-BUILDING NETWORK CHALLENGES

In this section, we identify two challenges facing in-building networks transitioning from 4G to 5G: making passive Distributed Antenna Systems (DAS) 5G ready and transitioning from lower to higher band within sub 6 GHz band.

3.1 BACKHAUL

Higher 5G peak data rates require higher backhaul throughput data as well. According to a recent Ericsson study [9], the backhaul throughput growth is going to slowly increase over the years, with only a fraction of sites requiring having the backhaul match the top 5G peak rate of 20 Gb/s by the year 2025:

Advanced Mobile Broadband	2016	2021	Towards 2025
80 percent of sites	90 Mbps	300 Mbps	600 Mbps
20 percent of sites	300 Mbps	1 Gbps	3-5 Gbps
Few percentage of sites	1 Gbps	3-10 Gbps	10-20 Gbps

Source: Ericsson 2016

Table 1: Backhaul capacity requirement per radio site for operators [9]

Macro sites mostly support high mobility users, while indoor sites support stationary or pedestrian users. As stationary users command higher throughput than mobile users, it follows that required backhaul throughput for indoor sites is much higher than for macro sites. As Table 1 represents combined backhaul requirements for outdoor and indoor sites, we expect to see a higher percentage of indoor sites with 3-10 Gb/s throughput by 2021 and with 10-20 Gb/s throughput by 2025.

If a planned in-building network is a small cell network, then required capacity throughput for each small cell is calculated based on estimated traffic load at the venue. The backhaul requirement for the whole network is a summation of required throughput for each cell. This requirement is compared to available dark fiber capacity in the building. If the available dark fiber capacity is insufficient, a wired network provider (outside plant) needs to be aware of the additional building capacity demands due to 5G network installation. If the available dark fiber capacity is sufficient, then additional in-building fiber optical network with passive optical splitters and fiber links between the main terminal room and small cells should be designed and included as a part of small cell network design package.

Designing an additional passive optical network to support backhaul (or in the case of C-RAN, fronthaul) throughput is a new requirement when it comes to planning and designing in-building networks. It is not sufficient anymore to worry only about where to put small cells, but also how to bring the required capacity from the main terminal room to them. Thus, designing small cell indoor 5G wireless network requires designing a supporting wireline network to give the small cells enough capacity to realize its full 5G potential.

3.2 MILLIMETER WAVE FREQUENCIES

The need for very high throughput has moved some operators to consider deploying 5G networks at frequencies much higher than the ones currently used in 4G networks. In the United States, FCC allows frequency bands at 24, 28, 31 and 39 GHz to be used for fixed broadband communications. In other parts of the world, operators experiment with 5G network trials at frequency bands going as high as 90 GHz. These frequencies are commonly referred to as millimeter-wave frequencies, even though technically millimeter wave frequencies are from 30 to 300 GHz. The advantage of using these bands is that millimeter wave spectrum blocks are much wider than sub-6 GHz band blocks, and thus allow much higher data rate, even without Beamforming and Massive MIMO. However, these bands are not suitable for blanket city-wide macro network deployment for several reasons:

- High free space pathloss
- Strict Line of Sight (LOS) is required for macro networks coverage
- No UE mobility support

Even with these restrictions, millimeter wave networks can be deployed at indoors venues that are mostly line of sight with few obstructions. An example of such venues is a stadium, where an RF transmitter deployed above the seating area ensures line of sight with spectators. Another example is an indoor hotspot, such as a cafeteria or a conference ballroom. Even though indoor use cases are very limited, we expect to see the first in-building 5G networks deployed at these frequencies.

3.3 MAKING PASSIVE DAS 5G READY

Passive DAS is still a very popular in-building architecture due to comparatively low deployment costs for small and medium-size venues, up to 100,000 square feet. It's especially popular in Asia, where most networks are still passive DAS. This architecture is depicted in Figure 6:

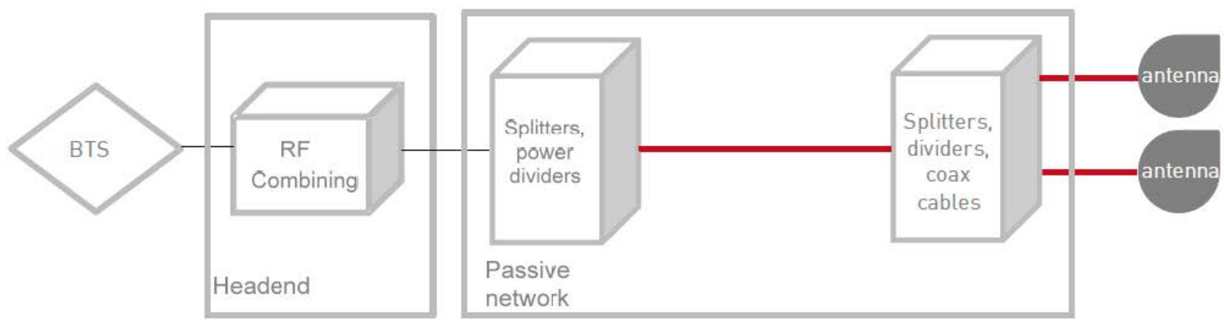

Figure 6: Passive DAS architecture

Even though passive DAS in the figure is very simplified with only 2 antennas, we can conclude that this network does not support MIMO. To support MIMO each antenna would need a separate cable all the way back to BTS. However, in passive DAS, the signal from antennas are combined close to antenna location, and the combined signal is sent on a single RF cable toward the base station, where signals from different branches are once again combined. Since the Base Station cannot discern the signal coming from different antennas, this makes it a SISO network. Even though 3GPP specifies mandatory 2x2 MIMO, many passive DAS 4G networks have been deployed in this SISO configuration, to cut the cost of the second coaxial run from 2 MIMO antennas all the way to BTS.

Converting these passive SISO DAS networks to 5G would first require installing new massive MIMO antenna panels, like the one shown in Figure 4 with 44 cross-polarized antennas. Then, a coaxial cable from each cross-polarized antenna in a panel should be installed all the way back to Base Station. This is not scalable, and due to inability to efficiently migrate to 5G, 4G passive DAS networks may be replaced by networks more fit for 5G, like fiber DAS or small cell networks.

3.4 MIGRATING FROM SUB 3 GHz TO SUB 6 GHz BAND

Mobile 5G networks are expected to operate in sub 6 GHz band. Millimeter wave band is reserved for fixed broadband, due to LOS limitation. As was the case with 4G, there won't be a single worldwide frequency band reserved for 5G. In some countries, a regulatory body may design a band specifically for 5G technology, to ensure that operators do not need to re-farm a 4G band to deploy 5G. In other countries, the governing body may not specifically assign any band as 5G band only, giving full control of the spectrum to spectrum auction winners.

In China, it was announced that the government allocated 3.5 and 4.9 GHz band for 5G. Previously, they allocated 4G bands at 1.8, 2.3, 2.5 and 2.6 GHz. Transitioning to 4.9 GHz would require replacing all antennas regardless of the 4G band, as current 4G antennas do not cover 4.9 GHz. Moreover, transitioning from 2.6 to 4.9 GHz would add 20log10(4.9/2.6) = 5.5 dB to 4G pathloss, while transitioning from 1.8 GHz would add 8.7 dB to the pathloss. This is a significant loss that might require adding more antennas to existing 4G networks. We do not know yet if Beamforming gain can make up for this additional loss, as 5G trials do not go into great technical performance details, such as beamforming gain. However, this pathloss delta should be kept in mind in countries like China, where mandatory 5G spectrum is double (or more) the frequency of the existing 4G spectrum networks.

4 CONCLUSION

In this paper, we presented three technologies that may have the biggest impact on in-building networks: Beamforming, Massive MIMO, and C-RAN. The basics behind each technology were described, and we explained how they impact the network. We also talked about how backhaul planning and designing of an in-building passive fiber network between the main terminal room and indoor small cell locations has become an integral part of planning for 5G indoor networks. We identified two instances when migration from 4G to 5G network might require either complete network replacement (Passive DAS) or adding antennas to fill in 5G coverage holes (4.9 GHz band). In the long run, we think that small cell and fiber DAS networks will be the only viable choice for 5G in-building networks.

When designing a 5G network, considerations for network density and network architecture increase the sheer scope of design and implementation of 5G in-building networks. To make the transition to 5G efficient a common platform for building survey, RF planning, design and maintenance should be used. iBwave has simplified this process to ensure optimization of in-building networks projects by helping to eliminate redundancies and ensuring the information is easily shared with all project stakeholders throughout the project lifecycle.

5 REFERENCES

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