The Evolution of the Cell Site: *Moving to the CRAN*

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Executive Summary

Although it may seem hard to believe today, the original concept of a cellular radio system was first proposed in 1947. The first modern cellular system was launched in 1979 and since then, cellular networks have been in an almost constant state of evolution.

Over the past four decades, cellular systems have evolved considerably but they are all built on the same basic components: subscriber/user devices; wireless/cellular licensed spectrum; cell sites which have antennas, radios, baseband units, and power supplies; connections that provide the wired links between the cell site radio equipment and the rest of the network; and a mobile core (Evolved Packet Core).

The original analog cellular systems (know referred to as 1G or 'first generation') simply used analog radio signals to connect between the user equipment and the cell site. In the early-1990s, the industry moved to second generation systems, characterized by the use of a digital air interface and an out-of-band signaling system. The efficiency, and therefore capacity, of these 2G systems also increased significantly over the original analog 1G networks. Also at this time, some cells were 'split' into multiple sectors, allowing for greater capacity with frequency reuse.

Third generation (3G) systems were introduced in the early 2000s and met the need for mobile data capability from the consumer. 3G systems features much-improved radios and base band units on the towers, new air interfaces and more backhaul capacity to move the data traffic from the cell site to the rest of the network.

The popularity of 3G mobile data services and the introduction of smartphones made it clear to the wireless industry that a more efficient network technology was required. The first 4G LTE (Long Term Evolution) networks were introduced in 2009 and 2010 in Europe, Asia, and the U.S. Several important changes were introduced by LTE, especially the RAN: much increased backhaul capacity to the cell; use of remote radio heads (RRH) on the tower; and use of MIMO (Multiple Input Multiple Output) antennas increases the capacity.

The use of RRH allows the baseband units to be separated from the radio. Hence, basebands can be centralized in a local data center or some other suitable location (this is only starting to happen now), reducing maintenance costs and easing the effort and cost of upgrades.

Today's challenges

As the subscriber base continues to grow strongly around the world, it is clear to the wireless industry that the next evolution of networks is required – 5G. The main driver of this evolution is the ever-increasing demand for mobile data capacity. The major underlying shift in consumer behavior is that today consumers select wireless devices first to complete a task (and assume a wireless connection will be available). For many, a mobile connection is the only one available, as many homes have disconnected their traditional landline phones. As a result of this 'wireless-first' trend, the pressure on mobile networks has increased significantly.

The type of content consumers expect to access on their smartphones and tablets has also changed significantly. Subscribers today access everything from email and social networking, to streaming long-/short-form video, to downloading apps and playing games. All of these activities, and many others, drive mobile data usage to a greater of lesser extent.

The last five years has also seen the rise of companies and services that rely exclusively on mobile networks for their source of revenue. Companies such as Facebook and YouTube now get the majority of their advertising revenue from mobile users. And Snapchat only exists on mobile devices.

The next cell site evolution

The move to 5G will result in fundamental changes to the architecture of the mobile networks to address the need for increased bandwidth and lower network latency. The basic goal of advanced LTE and 5G networks is to increase the cell density and move more application processing and content to the edge of the network. This will result in processing being distributed across the network, together with the need for 'edge data centers' to carry more of the load. Each request will not traverse the RAN and EPC (as happens today) but rather will be addressed at the edge of the network, as close to the cell site radio as practical.

*iG*R believes that three fundamental changes will change the basic architecture of the mobile networks in the next few years:

- **Massive densification with more small cells**. A wide range of small cell solutions will be needed to meet different locations, business needs and network demands. One component of this process will be to have small cell solutions that are pre-integrated and pre-tested, enabling a technician to quickly and easily deploy the cell. Network configuration will then be electronic, lowering the cost to deploy small cells. Small cells will be coupled with the deployment 'massive MIMO' solutions, further increasing the bandwidth available to the end user. MIMO orders of 8x8, 16x16 and higher will be common by the end of this decade.

- **Evolve the RAN to CRAN.** Centralized or Cloud RAN (CRAN) is a shift in network architecture from "distributed" macrocells each with their own base stations and baseband processing to a more centralized network architecture in which baseband processing happens on off-the-shelf server hardware that are in carriers' Central Office, Hub Location or data center location. Once the baseband are centralized, then radios/antennas can be placed anywhere – on conventional towers or in small cell sites.

Since there is a limit as to how far a RRH can be located from the baseband unit (BBU), BBU pooling locations will be required in basements of buildings or even at the side of the street (in a suitable enclosure).

Note that 'Cloud' and 'Centralized' are used almost interchangeably today when some refer to CRAN. In fact, Centralized RAN is the first step in the process (this is happening today), where the BBUs are pooled at a common location. Once this centralization has occurred, then the BBUs can be virtualized and Cloud RAN is deployed. Cloud RAN typically means off-the-shelf hardware can be used reducing deployment capital and operating costs. Cloud RAN is some way from being deployed however.

- **Mobile Edge Computing (MEC) solutions deployed at the edge of the network.** – MEC uses off-the-shelf hardware, allows application processors and content servers to be located at the edge of the network. The result is reduced network latency, improved end user experience and reduced content transport costs across the network.

  MEC components (there are many business models being proposed that will define multiple 'MEC appliances') will ideally be housed as close to the radio as possible. In reality, this is likely to be in the same location that houses the baseband processors for the CRAN.

- **Spawning a "Network of Networks"** – the increasing diversity of use cases that come into play with 5G will cause the mobile wireless network of today to evolve into a "network of networks." For example, there will be a network layer that is optimized for delivering "enhanced mobile broadband" services at data rates approaching 1 GBps using new spectrum at higher frequencies than are in use by today's mobile networks. There will be another layer that will be optimized to support the Internet of Things and its billions of connected sensors that will include low data rate, long battery life devices. The evolved packet core (EPC) will be segmented into layers through virtualization to support these different use cases.

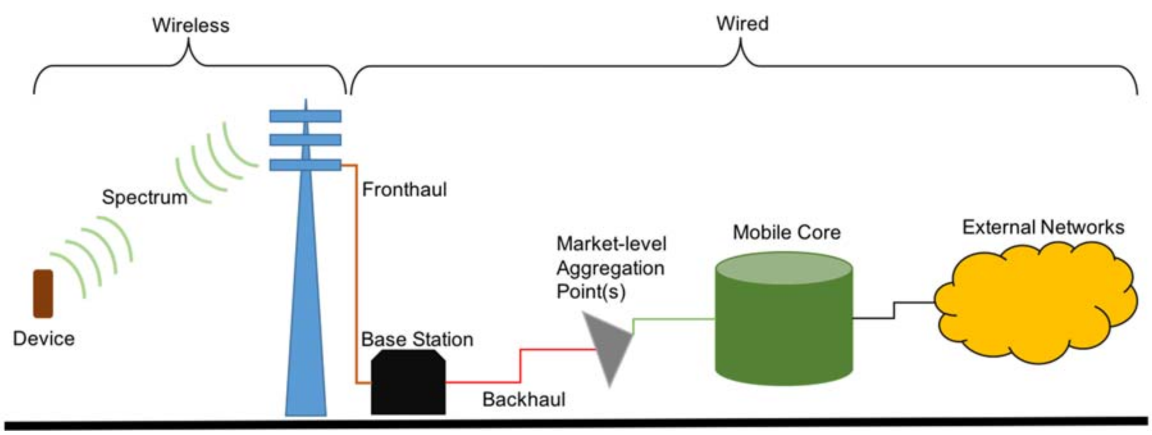
A historical view of cell sites

From the original concept of a cellular radio system, first proposed by engineers at Bell Labs in 1947, cellular radio systems have come a long way. Several innovations were needed to enable the first modern cellular system, launched by NTT in Tokyo in 1979 – these innovations included handoff of existing calls between cells, directional antennas, and frequency reuse.

Today, the wireless industry generally refers to cellular systems by generation – 1G, 2G, 3G, etc – although this approach was not widely adopted until third generation systems were deployed in the 2000s. The basic concepts of cellular systems have not changed in the last four decades – what has changed is the equipment used in the systems and how the systems are architected.

The following graphic shows a simplified view of some of the key components of mobile networks.

Figure 1: Basic Components of Cellular Voice/Data Network



Source: *iG*R, 2016

The basic elements of a cellular voice/data connection are:

- Subscriber devices of many different, evolving types – originally these were simple analog cell phones but today include smartphones, tablets, laptops and other devices.
- Wireless/cellular licensed spectrum – the first licenses were awarded by auction but mobile operators now pay billions for access to new airwaves. From the original cellular bands, spectrum is now used in the PCS, AWS, 700 MHz, WCS and 2.5 GHz bands.
- Cell sites: Although variable in size (and the terminology used to describe the various types), all cell sites have antennas, radios, baseband units, backhaul and power supplies.

- Fronthaul and backhaul provide the wired links between the cell site radio equipment and the rest of the network. Fronthaul describes the link between the baseband processing and the radios (which sit before the antennas). Backhaul describes the link between the cell site and the rest of the network. Essentially, all of the traffic from a single cell site travels over the backhaul connection - fiber is the most common method of cell site backhaul today (with some sites using microwave connections due to cost or location considerations) although copper (T1 and T3 circuits) were used more extensively in the past. Collectively, the cell site, front/backhaul and spectrum are referred to as the RAN or Radio Access Network.

- Note that as mobile operators move to Centralized RAN, the fronthaul network becomes much longer, essentially replacing the backhaul network as the long run between the cell site and the market aggregation points.

- The operator's mobile core, collectively called the Evolved Packet Core (EPC), which is basically responsible for switching and routing traffic within the cellular network and providing a connection to external networks. Historically, the mobile switching center (MSC) was the main component in the EPC.

Changes with 2G (digital)

The original analog cellular systems (know referred to as 1G or 'first generation') simply used analog radio signals to connect between the user equipment and the cell site. This allowed for easy eavesdropping on calls, was prone to interference and was also relatively inefficient. Some of the first analog systems were NMT (Nordic Mobile Telephony), AMPS (Advanced Mobile Phone System), JTACS (Japan Total Access Communications System) and TACS (Total Access Communications System).

The move to second generation systems was characterized by the use of a digital air interface and an out-of-band signaling system (proving support for messaging, call waiting, voicemail notification, etc). The efficiency of the systems also increased over analog, allowing for more simultaneous calls per cell site.

2G standards included GSM (Global Standard for Mobile), IS-136 (or TDMA or D-AMPS), IS-95 CDMA, JDC (Japanese Digital Cellular) and iDEN. While there were a range of standards in use and mobile operators quickly replaced the analog systems with 2G, little changed at the base station: backhaul from the cell site was still predominantly via copper circuits; antennas were at the top of the tower connected via coax to the radio and baseband at the bottom; and the majority of cells were single sector.

Some cells were 'split' at this time into multiple sectors (usually three), allowing for greater capacity with frequency reuse. The figure below shows common configurations for cell sites – note the three-sided array on top of the towers, one side for each sector.

Figure 3: Common Types of Cell Towers

Monopole

Lattice

Guyed

Stealth

Source: *iG*R, 2016

Changes with 3G (mobile broadband)

Third generation (3G) systems were introduced in the early 2000s and met the need for mobile data capability from the consumer. 2G systems introduced limited mobile data speeds plus text messaging became very popular. 3G systems features much-improved radios and base band units on the towers, new air interfaces and more backhaul capacity to move the data traffic from the cell site to the rest of the network.

Antennas at this time also started to include remote control for tilt (allowing remote adjustment to tune the network) and far more sophisticated multi-band support. More cell sites were split to add sectors and capacity, due to increased consumer demand for bandwidth. As a result of these changes, network capacity (both for voice calls and data connections) increased significantly over 2G.

Common 3G systems included UMTS (Universal Mobile Telephone System), EV-DO (CDMA Evolution – Data Optimized) and EDGE (an evolution of GSM, although many classified this as '2.75G'). The IMT-2000 specifications, defined by the ITU, determined the requirements of a 3G system.

Changes with 4G (LTE)

The popularity of 3G mobile data services and the introduction of smartphones made it clear to the wireless industry that a more efficient network technology was required. There was also a need to have one standard used by all major mobile operators across the globe, to provide efficiencies of scale for network equipment and devices.

LTE (Long Term Evolution) was first introduced by TeliaSonera in 2009, followed by China Mobile and Verizon Wireless in 2010.

When LTE was deployed, several important changes were introduced into the cellular networks, especially the RAN:

- Much increased backhaul capacity to the cell, including use of fiber as 'standard' – note that some mobile operators started installing fiber bundles to cell sites at the end of the 3G era in anticipation of 4G and future standards.
- Use of remote radio heads (RRH) on the tower – the RRH sits on the tower, as close to the antenna as possible. A fiber then connects the RRH to the baseband unit at the bottom of the tower. This architecture minimizes power losses (since the use of leaky coax is minimized), saves electrical power and reduces the size of the radio that is necessary.
- Since the baseband unit is separated from the radio, basebands can be centralized in a local Central Office, Switching Center, Hub Location or data center or some other suitable location (this is only starting to happen now). This reduces maintenance costs and also eases the effort and cost of upgrades.
- Use of MIMO (Multiple Input Multiple Output) antennas increases the capacity of the air interface between the tower and the user equipment. 2x2 MIMO means two transmit antennas (base station) and two receive antennas (device). 4x4 MIMO means four transmit antennas (base station) and four receive antennas (device).

The challenges today

While LTE has been very successful (the subscriber base continues to grow strongly around the world), it is clear to the wireless industry that the next evolution of networks is required. This is 5G or fifth generation. The main driver of this evolution is the ever-increasing demand for mobile data capacity.

The major underlying shift is consumer behavior is that consumers today select wireless connections first (and assume they will be available). For many, a mobile connection is the only one available, as many homes have disconnected their traditional landline phones. As a result of this 'wireless-only' trend, the pressure on mobile networks has increased significantly.

At a high level, there are several "macro" factors that influence mobile data demand:

- **Population and connections** - as a result of the increasing population, the increasing adoption of multiple mobile devices such as tablets, the expected growth of the connected car market, and the growing number of devices in the Internet of Things (IoT), *iG*R forecast that global mobile connections will grow steadily, reaching almost 9.34 billion by the end of 2020. Thus, the penetration rate will increase from its current 100 percent to 122 percent. Note that this means that each person on average will have 1.2 mobile devices.

- **Networks** – 2G networks will be decommissioned over the next few years, the spectrum being reused for LTE. And 3G connections are forecast by *iG*R to decline at a CAGR of -16.8 percent through 2020. Conversely, 4G LTE is still in relatively early stages of deployment and will see very high growth: 4G is expected to grow to 470 million connections by 2020 at a CAGR of 16.3 percent.

- **Devices** – in addition to smartphones, consumers today are demanding mobile data connections for their tablets, cars, gaming devices, e-readers, smart watches and fitness bands and a range of other devices. Every device has a screen and more screens results in higher data usage. In addition, Internet of Things (IoT) devices and solutions are increasingly being deployed, including everything from home security systems to mobile healthcare. Note that mission critical applications and services need low latency connections between the device and network.

- **Price** - prices for mobile voice and data vary between mobile operators and also by the type of rate plan the consumer uses. To further complicate the issue, many consumers have 'grandfathered' plans which may be no longer available to new customers. Family rate plans and shared mobile data plans have become very popular. The highly competitive nature of the wireless market means that mobile operators are increasingly pressured to offer more data for little or no additional revenue. Couple this with consumers' increasing inability (or unwillingness) to pay more for mobile service and it is clear the mobile industry must find new sources of revenue.

- **Content** - this is a broad area comprising everything from email and social networking, to streaming long-/short-form video, to downloading apps and playing games. All of these activities, and many others, drive mobile data usage to a greater of lesser extent. Generally speaking, the availability of content on the Internet is what drives interest in, and usage of, smartphones, other connected devices, and mobile data.

- **Business models relying on reliable mobile connectivity** – the last five years has also seen the rise of companies and services that rely exclusively on mobile networks for their source of revenue. Companies such as Facebook and YouTube now get the majority of their advertising revenue from mobile users. And Snapchat only exists on mobile devices.

Where cell sites go next

The move to 5G will result in fundamental changes to the architecture of the mobile networks – it is interesting to note that while the air interfaces has evolved and improved from 2G to 4G, the same basic network architecture is still used. To address the need for increased bandwidth and lower network latency, fundamental changes are needed to how mobile networks are architected.

The basic goal of advanced LTE and 5G networks is to increase the cell density and move more application processing and content to the edge of the network. This will result in processing being distributed across the network, together with the need for 'edge data centers' to carry more of the load. Each request will not traverse the RAN and EPC (as happens today) but rather will be addressed at the edge of the network, as close to the cell site radio as possible.

*iG*R believes that three fundamental changes will change the basic architecture of the mobile networks in the next few years:

- **Massive densification with more small cells** - many mobile operators are evolving their cellular-only radio access network (RAN) to an integrated network that includes small cells (femto, pico, metro, micro), DAS and enhanced WiFi technology, remote radio heads (RRHs) and active antennas. A wide range of small cell solutions will be needed to meet different locations, business needs and network demands.

  Deploying small cells today has many challenges including cost, location, zoning and planning, and the availability of suitable backhaul and power. The goal for the mobile industry in the next few years to industrialize the deployment of small cells in a wide location of locations, so that they can be deployed by the tens of thousands, not just a few hundred at a time.

  One component of this process will be to have small cell solutions that are pre-integrated and pre-tested, enabling a technician to quickly and easily deploy the cell. Network configuration will then be automatic, lowering the cost the deploy small cells. Small cells will be coupled with the deployment 'massive MIMO' solutions, further increasing the bandwidth available to the end user. MIMO orders of 8x8, 16x16 and higher will be common by the end of this decade.

- **Evolve the RAN to CRAN** - simply put, CRAN is a shift in network architecture from "distributed" macrocells each with their own base stations and baseband processing to a more centralized network architecture in which baseband processing happens on off-the-shelf server hardware that are in carriers' data centers. Once the baseband are centralized, then radios/antennas can be placed anywhere – on conventional towers or in small cell sites.

  Since there is a limit as to how far a RRH can be located from the baseband, the shift to CRAN will necessarily require the deployment of more local data centers (the concept is not unlike the old Central Offices). This means that data centers will be required in basements of buildings or even at the side of the street (in a suitable enclosure).

Virtualization of the baseband means that the current one radio-one baseband processor will be broken. This, and the use of off-the-shelf hardware for the baseband, will reduce deployment capital and operating costs. The final benefit is added flexibility, with the operator able to 'switch' capacity to different parts of the network as needed.

- **Mobile Edge Computing (MEC) solutions deployed at the edge of the network** – MEC is an ETSI standard that, using off-the-shelf hardware, allows application processors and content servers to be located at the edge of the network. As well as reducing network latency, MEC also improves the end user experience and reduces the transport costs across the network (for example, a popular movie can be cached at the edge of the network, reducing the time taken to download and removing the need to send the content over the entire network each time it is accessed).

  MEC components (there are many business models being proposed that will define multiple 'MEC appliances') will ideally be housed as close to the radio as possible. In reality, this is likely to be in the same data center that houses the baseband processors for the CRAN.

Methodology

*iG*R relied on the following sources when writing this whitepaper:

- Discussions with vendors in the industry
- *iG*R's primary research, reports and forecasts
- Secondary research.

Disclaimer

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About *iG*R

*iG*R is a market strategy consultancy focused on the wireless and mobile communications industry. Founded by Iain Gillott, one of the wireless industry's leading analysts, we research and analyze the impact new wireless and mobile technologies will have on the industry, on vendors' competitive positioning, and on our clients' strategic business plans.

A more complete profile of the company can be found at http://www.iGR-inc.com/.