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Can 5G Bridge the Urban-Rural Digital Divide?

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Key Takeaways

1. 5G equipment come in a large variety of features and options to address different deployment scenarios – more so than any previous cellular technology. Rural service providers need to carefully define their objectives and assess the available options to decide on the best cost-performance trade-off for their deployment scenario.
2. Rural service providers may not be able to leverage the full potential of 5G technology. In fact, some rural operators, especially those with small spectrum holding, may find 4G/LTE offering attractive cost structure albeit at a lower performance than 5G.
3. Incumbent service providers have a decisive edge in deploying 5G in rural areas because they own spectrum in sub 2 GHz bands. This is important for two reasons: a. The sub 2 GHz spectrum when used for LTE serves as a base to quickly roll out 5G in mid-band spectrum (e.g. 3.5 GHz); and b. The sub 2 GHz spectrum could be used to increase the coverage of 5G which is severely limited in the uplink in contrast with the downlink.
4. Equipment vendors have an opportunity to develop special 5G solutions for rural areas. To date, the focus of 5G has been on urban areas with solutions that provide a capacity layer for broadband mobility applications. The equipment market for rural 5G products is yet to develop – provided vendors see a business case in it.

Overview

5G technology brings a new hope to bridge the digital divide between urban and rural areas. This has been the case with every cellular technology which raises the question of how and why 5G is different. This paper is a partial summary of a study to evaluate the techno-economic characteristics of 5G networks in rural areas. Here, we focus on distilling the consequences of key 5G technical characteristics on rural markets, while leaving the economic aspect to a future publication.

5G: What's Different

5G features a flexible architecture designed to enable a different deployment scenarios and use cases. The leading use case today is urban area capacity layer where operators are in process of deploying 5G radios in mid-band spectrum (2.5 GHz and 3.5 GHz). Rural applications of 5G have attracted the interest of governments and the public. The headline advertisements of gigabits per second (Gbps) speed are very attractive. To achieve Gbps speeds, 5G relies on three pillars:

1. Wide spectrum allocations. 5G takes advantage of large spectrum allocations in mid-band spectrum to operate in a 100 MHz channel bandwidth. This amount of spectrum is not available below 2 GHz. Moreover, the operation in mid-band spectrum is based on time division duplex (TDD) mode as opposed to frequency division duplex (FDD)

mode in low spectrum bands. TDD allows a higher downlink traffic (from base station to subscriber) ratio than uplink traffic (from user to base station) (Figure 2).

2. Massive antenna systems. MIMO antenna systems which were developed in the mid-to-late 1990's came into maturity in 4G technology. While 2 or 4 transmit/receive antennas are common in 4G, 5G extends this to 64 transmit/receive antennas (Figure 1). Moreover, 5G combines MIMO technology with beamforming to further enhance performance in urban areas with tall buildings where horizontal and vertical beamforming provide additional gain.

   Massive MIMO benefits from RF signal scattering to increase capacity. Urban areas provide a rich scattering environment from buildings and other structures. Additionally, these antenna systems reduce interference, especially when combined with beamforming.

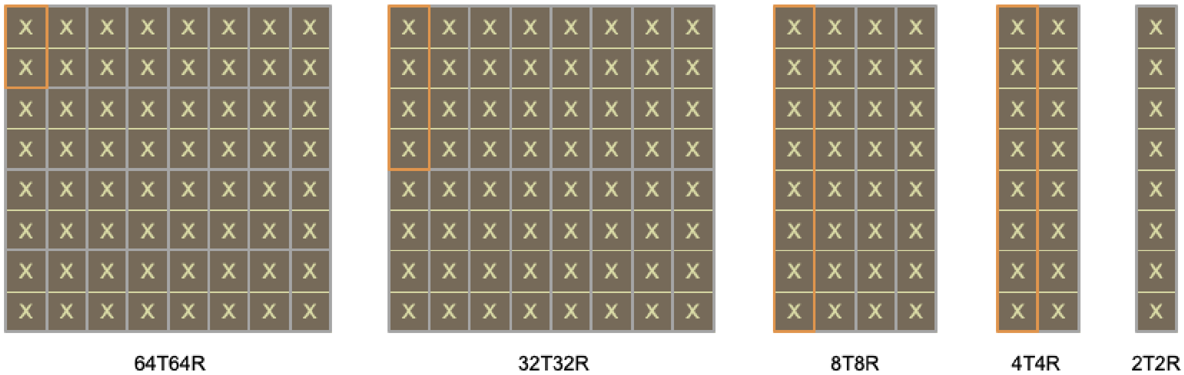

Figure 1 MIMO Antenna systems in 5G.

3. Modulation and coding: 5G further enhance the channel coding and error correction schemes to improve communication in the presence of interference or at long range.

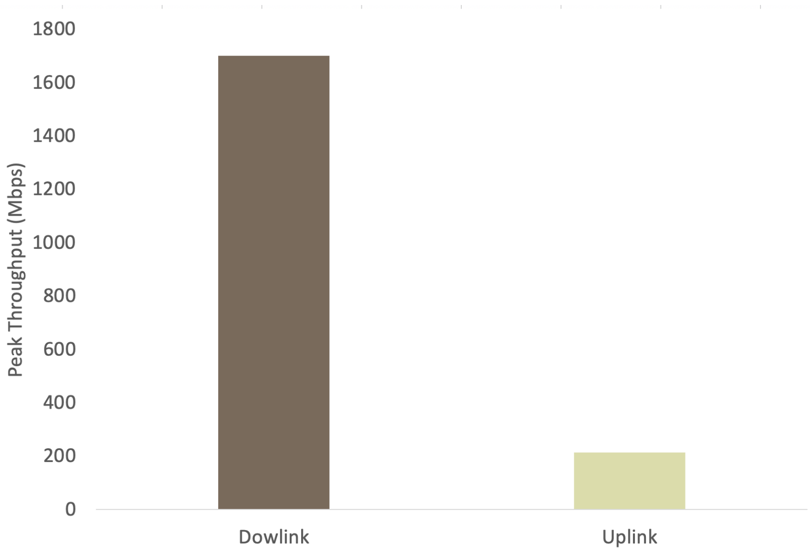

Figure 2 Peak throughput for 100 MHz carrier in 3.5 GHz with 75:25 traffic ratio; 4-layer MIMO in downlink and 2-layer MIMO in uplink.

As a result, 5G offers a wide range of options – number and type of antennas, operating bands and modes, power settings, etc. The viability of these options will depend on the deployment scenario, the type of service provider and the frequency spectrum among other factors. We highlight some examples in this paper.

Note that 5G provides many other differences from prior technologies for both the radio access and the core network. However, we limit the discussion here to the most pertinent aspects for rural coverage.

Rural vs. Urban Deployments

5G could be used for mobile or fixed wireless access services. In a rural context, mobile network operators as well as fixed wireless access or wireless Internet service providers could leverage 5G. We highlight this distinction because different types of service providers will have different financial, operational and technical capabilities. 5G was designed for the mobile network operators, although it is possible for other classes of service providers to leverage 5G.

In rural areas, service providers, irrespective of the type, desire wide area coverage to efficiently amortize capital and operational costs. This contrasts with deployments in urban areas where capacity is prized foremost. The different objectives lead to different requirements and economics for the two areas.

5G System Options in Rural Areas

The open landscape of rural areas reduces RF scattering and nullifies the capacity gain of massive MIMO 64T64R and 32T32R antenna systems. In open areas, the capacity gain of these systems is reduced to that similar to low-order MIMO systems such as 4T4R, or even 2T2R. This led different parties to suggest deploying only low-order 4T4R/2T2R MIMO systems in rural areas, or perhaps 8T/8R which offers limited beamforming capability. However, high-order MIMO systems still provide system gain from beamforming that works to extend range above that for low-order MIMO systems (Figure 3). Rural service providers would therefore need to carefully consider the tradeoffs in selecting 5G equipment. This includes Open RAN solutions, some of which target rural markets[1].

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1 Our analysis of the evolution of Open RAN systems based on O-RAN Alliance-specified interfaces point to different trade-offs that affects the proliferation of 5G Open RAN solutions in rural markets – a topic that we leave for another publication.

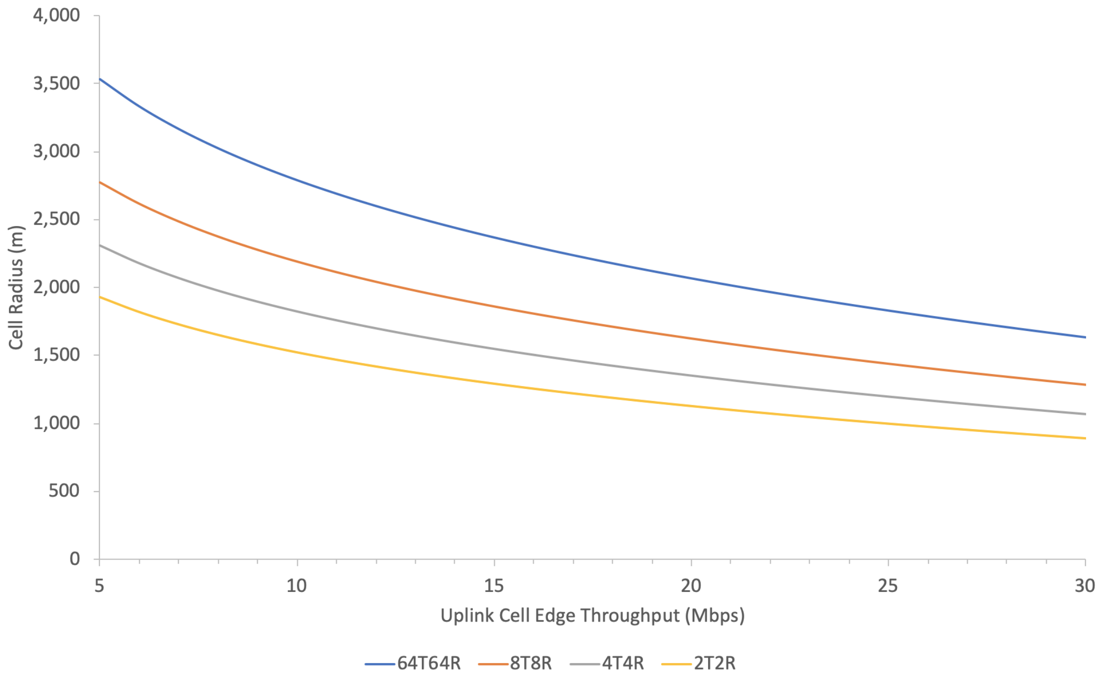

Figure 3 Range performance for different 5GNR antenna configurations in 3500 MHz. While 64T64R show the longest range because of the combining effect of the antenna array, it would provide little to no capacity benefit in open rural areas.

The plethora of antenna systems available in 5G highlights the focus of the telecom industry on serving urban areas. As mentioned above, MIMO technologies benefit from high RF scattering present in urban settings. In contrast, rural areas benefit from beamforming technologies more than they do from MIMO because the low RF signal scattering in rural areas. We find [almost] no 5G solutions that optimize the system architecture for rural environments. This is potentially an area that vendors can address in the future, just as some vendors adapted LTE for rural markets. In LTE, some vendors chose to integrate complete site solutions, including backhaul and ancillaries, to optimize the cost structure (e.g. Huawei), while vendors opted to strip LTE of its mobility features (typically smaller companies)[2].

The Spectrum Factor

The mid-band 3.5 GHz spectrum is the most popular band for 5G deployments where it is possible to assign a large bandwidth allocation, e.g. a single 5GNR carrier of 100 MHz. The relatively short wavelength of mid-band spectrum (order of 10 cm) makes it physically practical to deploy massive MIMO antenna systems while keeping the size of antennas manageable (e.g. a panel of about 1 m x 0.5 m).

2 For the most part, rural WISPs rely on variation on Wi-Fi or proprietary solutions that offer lower cost points than LTE.

Mid-band spectrum typical operates in TDD access mode. This makes it practical to implement massive MIMO and beamforming technologies because of downlink-uplink channel reciprocity. The same argument could be reversed for low band spectrum where it is impractical to deploy massive MIMO systems.

5G in mid-band spectrum has several weaknesses that become apparent in rural settings. These shortcomings include:

Short range: It is well understood that mid-band frequencies such as 3.5 GHz has shorter range than low frequency spectrum (Figure 4) and is less capable of penetrating foliage or other types of materials.

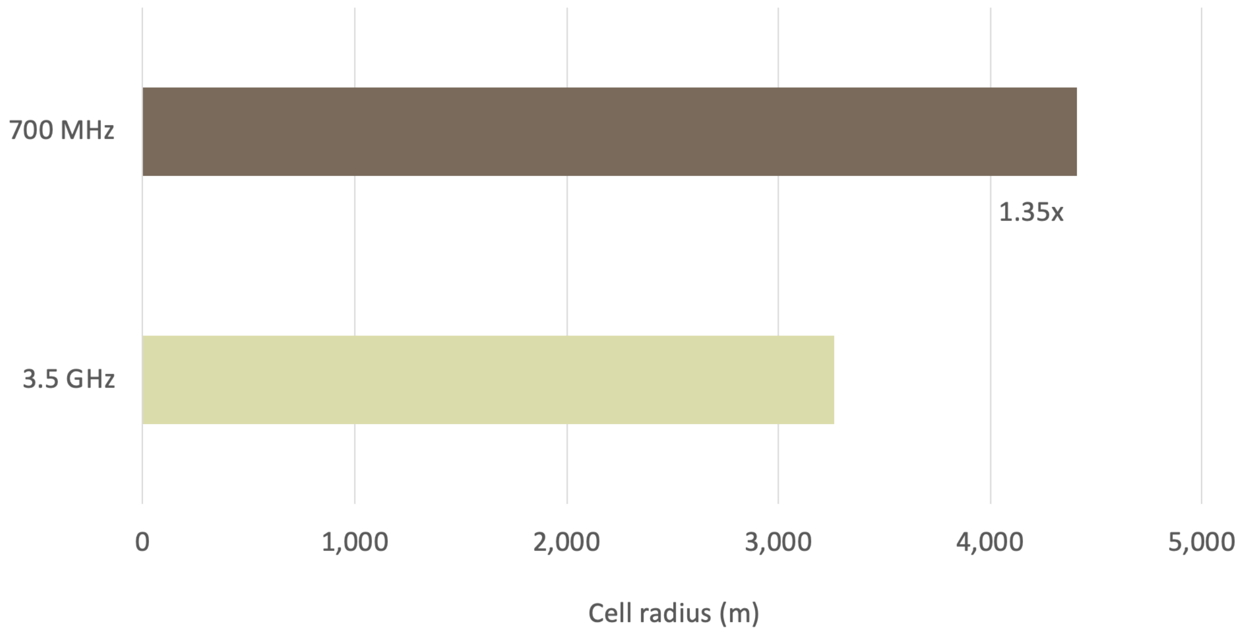

Figure 4 Range comparison between 2x10 MHz carrier in 700 MHz and 20 MHz 5GNR carrier in 3.5 GHz. Both are based on 4Tx4Rx antenna system.

Link imbalance: 5G suffers from a large path imbalance where the uplink system gain is between 16 – 22 dB less than the downlink system gain. To illustrate the magnitude of this difference, a 16 dB difference would increase the coverage range by 2.6x. This shortfall limits the operating range of 5G networks in rural areas where coverage is highly prized.

Part of the reason for the path imbalance is the scalability of base station antennas that leads to high output power in contrast with the limited number of antennas and output power of user devices. To overcome this challenge, operators could combine a low-band uplink signal, such as 1800 MHz. But doing so is only possible for mobile network operators and service providers with different spectrum holdings. Wireless ISPs and small rural service providers who lack low-band spectrum would need to build more 5G cell sites, which makes it economically challenging.

Power Requirements

5G equipment consume a lot of power! A first generation single carrier 64T64R massive MIMO radio with 200 W RF output power consumers around 1,400 W in normal operation. This corresponds to 14% power efficiency. An urban site would use 3 such radios for a total of 4,200 W. Newer generation radios with more advanced electronics improve upon this performance. However, the power efficiency remains in the range between 20%-30%.

While lower MIMO-order radios are sufficient for rural areas, as discussed above, the power consumption could still be between 200 – 800 W per radio, leading to site power requirements between 800 – 2600 W. This is the price to pay for capacity which comes from wide bandwidth spectrum allocations: power consumption scales with the bandwidth[3]

Power requirements lead to additional costs for backup batteries and/or diesel generators that smooth out grid power interruptions. 5G will require more backup power to maintain the same service level agreement. Green energy solutions such as solar panels which are an option where power consumption is relatively low – e.g. order of a few hundred Watts – quickly become unviable for wide-bandwidth 5G sites.

Core Network Considerations

5G is deployed in stages starting with a radio overlay on top of 4G networks. In this first stage, it will be necessary for the operator to have an existing LTE core network. In the second stage of 5G deployments, a standalone 5G core enables new features and services. The type of core network is a topic that's best left for a future publication. Here, we'd like to note that virtualization of the core network helps to lower the cost of 5G rural deployments. Virtualization allows 'low-end' scalability where it's economical for the core network to support relatively small number of subscribers. This helps rural and small operators improve the economic viability of the deployment.

Virtualization also enables new business models such as core network as a service. Moreover, the architecture of the 5G core supports control and user plane separation and network slicing which would help service providers leverage their core network infrastructure to serve rural areas with fixed access 5G service.

Transport Network Considerations

The transport network connecting 5G rural cell sites to the core network is a critical cost item. It often represents the foremost challenge in meeting the business case for rural and remote area service. This topic deserves more coverage than we can say in this paper. However, we note that the cost of transport increases with bandwidth requirements. Fiber is often not available in rural areas, and microwave becomes the only option. Supporting Gbps throughput is possible with more wireless bandwidth, which in turn shrinks the range of wireless backhaul link. This could translate into more hops and higher cost.

3 The US power density limit for C-band spectrum in rural areas is 3280 Watts/MHz for equivalent isotropically radiated power (EIRP) per sector.

Device Considerations

5G devices come at a price premium in comparison with LTE since they incorporate the latest system-on-chip (SoC) solutions. This applies to all type of devices, including those for mobile and fixed wireless access. As volume ramps up, price is expected to decline in the future. We would also expect more variety and types of devices to come to market catering to different types of deployment scenarios. For instance, typical devices are Class 3 with a 0.2 W power limit. Class 3 devices increase the limit to 0.4 W to provide greater coverage in select frequency bands including 2.5 GHz and 3.5 GHz.

Comparing 5G with LTE

The advantage of 5G over LTE depends on the operating spectrum. In the sub 2 GHz bands, 5G provides marginal improvement in spectral efficiency for 2T2R and 4T4R antennas. However, it is in the mid-band spectrum where 5G differentiates itself from LTE, primarily on the basis of massive MIMO and large carrier bandwidth (100 MHz for 5G vs. 20 MHz for LTE). But even here, one needs to carefully consider 5G advantages in the context of rural deployments. For instance, we have seen that massive MIMO technology has little capacity benefit in open and rural areas. Moreover, for rural service providers with small spectrum allocations such as 20 or 40 MHz, the performance improvement of 5G over LTE diminish further [4] (Figure 5). This scenario applies to the CBRS band in the US where, today, most CBRS equipment are based on LTE. We need to wait and see how quickly CBRS 5G equipment will come to market and proliferate.

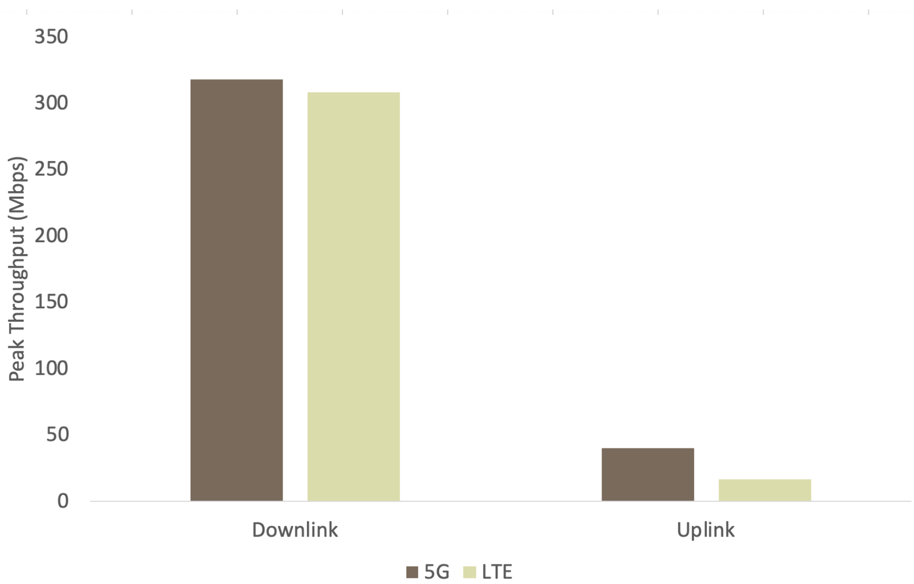

Figure 5 5G versus LTE peak throughput for a TDD 20 MHz channel, 4Tx4Rx MIMO, 75:25 traffic ratio. Both cases use 256 QAM in downlink and 64QAM in uplink. Uplink LTE has 1 MIMO layer while uplink 5G has 2 MIMO layers.

4 In comparing 5G with LTE, one needs to consider the practical versus the theoretical. The practical side is what is available on the market and what can come to market in a reasonable timeframe. The theoretical part is what the 3GPP standards define: possible, but not necessarily implementable for various considerations!

Integrating LEO Satellites and HAPS

The integration of low earth orbit (LEO) satellites and High Altitude Platform Systems (HAPS) into 5G networks is an important development for the coverage of rural areas. LEO satellites are becoming an option in certain regions of the world led by SpaceX Starlink. However, Starlink targets fixed wireless access services with a dedicated user terminal. Other constellations are targeting users with mobile terminals such as AST SpaceMobile, Lynk, and a few others, all of which are yet to launch commercial service. High Altitude Platform Systems (HAPS) received a setback after Google Loon terminated its activities due to high costs. We can anticipate that the next generation of LEO satellites and HAPs to integrate better into terrestrial wireless networks. There are few technical barriers to achieving this, with the highest barriers being the commercial aspects.

Conclusions

5G is unique in comparison to earlier cellular generations in that it offers a wide range of options that cater to different deployment scenarios. This raises the needs for service providers to carefully consider their deployment objectives to select the appropriate solutions to optimize the cost-performance trade-off.

As it stands today, the focus of 5G has been on providing a capacity layer for urban areas. While 5G has the features and options to serve rural areas, solutions targeting rural markets remain limited in availability. This presents an opportunity for vendors to offer differentiated solutions to help bridge the urban-rural digital divide.

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