

case study

Mixed Environment
Operator-only Business Model
2.5 GHz Macro Access

1 INTRODUCTION

The C Spire Rural Broadband Consortium is exploring how different business models and technologies can be used to enhance the feasibility of broadband deployment in rural markets. C Spire (the Operator), in conjunction with Nokia (Network Vendor), deployed a Band 41 (2.5 GHz) macro site to evaluate massive MIMO (mMIMO) feasibility as a broadband technology in mixed rural markets (which include two small towns with surrounding farming communities and scattered homes) as well as the cost impact of using advanced antennas. This case study describes the deployment with an operator-only business model and the results.

2 MARKET DESCRIPTION

The trial location in rural Mississippi area includes 2 small towns of around 500 pops each (circled on **Figure 1**), spaced less than a mile from each other, one with more closely spaced businesses and homes and the other more loosely organized with a smaller town center. Suburban-like neighborhoods are spread between and around the town centers. An Operator owned macro tower (marked with a triangle) sits in the more loosely organized small town and is fed with Operator-owned fiber. The more densely clustered small town is located to the west of the macro tower. The remainder of the areas around the macro tower is made up of scattered homes, some in loosely organized neighborhoods, some scattered farmhouses interspersed with fields, forests, and some mildly hilly terrain, resulting in many houses which do not have line of site (LOS) to the tower. Because of the varying (yet still low) population densities within the target service area, this environment can be considered a mixed rural environment.

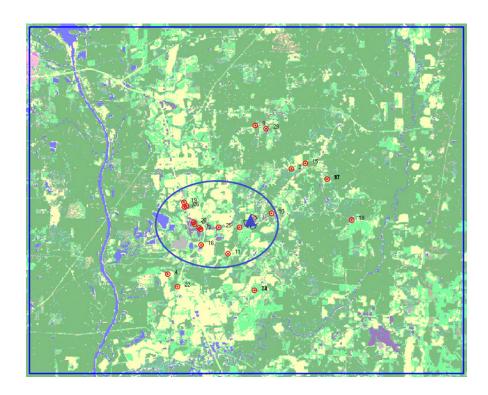


FIGURE 1: Massive MIMO Area Overview

Twenty consumer locations distributed both around town and into the farming community are indicated with red circles in Figure 1, to illustrate typical locations where households could be interested in receiving service. The scattered homes northeast of the tower are all 1-2 miles apart from each other. Due to the proximity of both towns to the macro tower, some of the consumer locations are LOS to the tower, though some are also non-LOS (NLOS). This scenario is of interest because the small towns provide a good anchor cluster of potential consumers, as well as improved infra-structure. At the same time, the long range and high capacity attributes of LTE mMIMO technology allows the surrounding areas to be covered and served, allowing the costs of the radio technology to be shared amongst a larger set of customers, and so reducing the cost per consumer. While there appears to be some fiber infrastructure in the area (including the Operator's) and cable service within the small towns, giving better than 25/3 Mbps service in those towns, the surrounding remote areas are primarily served by satellite.

3 TECHNOLOGY OPTIONS

While there are many technology options available, the mixed characteristics in this rural environment challenges most technologies, which in turn causes economic challenges. With fiber backhaul already located at the macro tower in the smaller town, only an access technology needs to be selected. The following is a list of access technology options considered:

• DIRECT FIBER ACCESS

- o Location of existing fiber assets and possibility of reaching any of the towns or homes
- o Pros: High speed, reliable, and a long useful lifespan
- o Cons: Expensive to bore more than 23 miles to connect every user

MACRO FIXED WIRELESS ACCESS

- o Existing Operator-owned fiber fed macro tower located in one of the small towns and within 4 miles of all identified consumers.
- o Pros: Enables large coverage area with the right spectrum and technology
- o Cons: Terrain and morphology restrictions limit spectrum and technology capabilities

• LEO SATELLITE ACCESS

- o LEO satellites will be appropriate for access to scattered homes or community sites far from existing network infrastructure
- o Economical for backhaul to medium to low density areas, easy to deploy, eliminates challenges related to LOS, foliage, and terrain
- o Cons: Not currently available; more expensive than other access solutions, especially due to consumer proximity to existing Operator assets¹

An analysis for using LEO satellite access was not run for this case study, see [2] for an example analysis.

MICRO FIXED WIRELESS ACCESS

- o Existing Operator fiber fed macro tower is 2 miles or less from two small towns, enabling wireless backhaul to these areas. Micro-cellular design relies on closely spaced buildings.
- o Pros: Could effectively serve clustered towns with reasonably high speed and reliability and low cost.
- o Cons: Not scalable for widely scattered houses

4 MARKET DESIGN

4.1 DESIGN

The mixed environment being targeted for service creates challenges for technology selection. While some technologies can serve part of the area, trying to serve all of the surrounding area means that a mix of types of technology solutions is likely needed. [1] In this case, one technology was able to serve most but not all the targeted consumers.

Using fiber access to serve consumers in this area is feasible. The consumers in the small towns are relatively easy to reach from existing Operator fiber, and a design that minimizes distances to reach the scattered homes with the least amount of new fiber possible was created. To serve the 5 closest out of town homes, 6.64 miles of fiber would be needed, compared to just 0.62 miles of fiber for 5 in town homes. It is also 166% times more expensive to serve the out of town homes. However, building more than 23 miles of fiber to serve both towns and scattered homes is cost prohibitive.

A micro-cellular deployment is also feasible and more cost-effective than fiber when used in the small towns. However, a micro-cellular network requires structures spaced within 500 feet and line-of-site with each other, making it not technically feasible to use micro-cellular infrastructure to serve the more loosely scattered houses.

The macro fixed wireless deployment is therefore the most technically feasible and cost-effective option currently available to serve this mixed morphology environment, and Band 41 mMIMO was viewed as the most likely single technology/band capable of serving the area most effectively. When designing a Macro Fixed Wireless Access Network, a necessary decision in the design phase is whether to utilize unlicensed frequencies or licensed frequencies. There is a wide variety of macro technologies and spectrum that can be used, from low- or mid-band LTE to unlicensed mid-band proprietary technologies. In this market's mixed environment, licensed LTE access technology in the 2.5 GHz band (Band 41) was chosen as the Operator controls spectrum in that band and uses LTE for mobility. However, in an environment where the Operator does not own (and cannot lease) spectrum, an unlicensed macro technology such as a Wi-Fi-based or proprietary 5 GHz solution would be necessary. Due to the LOS restrictions of the unlicensed 5GHz spectrum and limited allowable power (compared to licensed spectrum), the coverage and serviceable users decrease dramatically. Only about 5-6 of the selected consumers could be served from the Operator's existing macro site. In order to reach the rest of the users, an estimated 5-7 total 5GHz Macro towers would be needed, which would mostly be new tower builds. As a result, NLOS capability is a must, suggesting that licensed frequencies below 3 GHz are necessary for both propagation and higher transmit power. In addition, because of existing broadband internet service available in the small towns, enhanced throughput capabilities in the range of 100/10Mbps (DL/UL throughput), are desirable, indicating the need for the higher capacity and advanced antenna capabilities.

4.2 MASSIVE MIMO TECHNICAL DESIGN

Nokia's massive MIMO solution is the optimum technology choice for the mixed environment scenario. The parameters of the massive MIMO solution include the following:

- TD-LTE B41 (2.5 GHz)
- Downlink carrier aggregation with 3x 20 MHz Bandwidth
- 3 sectors of 64T64R mMIMO radio

Figure 2 shows the coverage map using the mMIMO macro, with the following coverage levels:

- Red area is RSRP Level > -101.5 dBm (100 Mbps downlink, 10 Mbps uplink)
- Green area has RSRP between -104.5 dBm to -101.5 dBm (50 Mbps downlink, 5 Mbps uplink)
- Blue area has RSRP between -106.8 dBm to -104.5 dBm (25 Mbps downlink, 3 Mbps uplink)

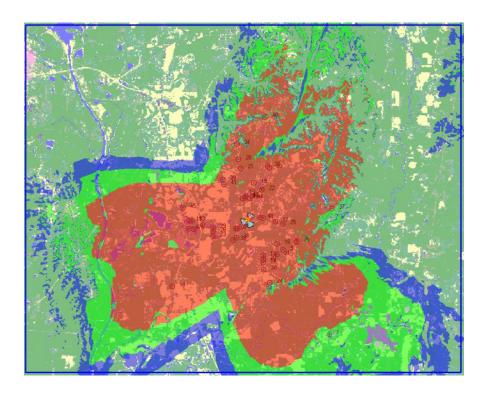


FIGURE 2: Massive MIMO coverage

Having all the consumers located in the red zone improves the overall capacity of the radio access solution. High signal strengths allow more spectrally efficient modulation coding schemes to be used, and so more data can be transmitted in the allocated amount of spectrum, enabling higher data rates. Note that there is one consumer (location 18) that falls outside all zones; that user sits in a small valley, with terrain that blocks even NLOS signals. That consumer will need to be served a different way.²

² Note that coverage modeling for a simpler 2T2R Band 41 radio indicates that six of the identified consumers would lack coverage, while for a more typical (mobility) 8T8R Band 41 radio, 3 of the consumers would lack coverage. Location 18 is included in both counts.

Massive MIMO technology can increase the spectral efficiency of LTE radio access, allowing more customers to be served with a fixed amount of spectrum. In macro cell style deployments with high towers, coverage from the tower is relatively large, but the tower installation is expensive. In order to lower the cost per consumer, as many customers as possible within the coverage area need to be connected, and so the radio access solution must have sufficient capacity to serve all these customers. This is why mMIMO solutions work so well in dense urban and urban environments. Using mMIMO in rural areas is a new use case, whose performance and potential cost benefits are being verified by the consortium.

Massive MIMO solutions allow multiple radio beams to be created in each sector, and the frequency/ spectrum resources to be re-used over and over in each beam. Beams can be formed in both the azimuth and elevation planes depending on the antenna design. This beamforming capability is the mechanism that increases the capacity of the solution. The technology is more effective when the instantaneous radio conditions are well characterized, and these conditions are well met in fixed wireless access where the end user stations do not move. Use of TDD duplexing also improves efficiency, as the downlink and uplink radio channels are reciprocal, and this increase the accuracy of the beam forming. One example mode of operation is 3GPP transmission mode 8 (TM8), where up to 8 beams can be formed in each sector, and each beam can be operated in 2x2 MIMO mode on the downlink. In a more typical deployment, the average number of beams that can be generated based on the radio conditions is less than 8, significant gains of the order of 3 or more may be achieved, depending on the angle spread of the consumer locations. Covering locations both close to the tower (e.g. in town) and more distant (farming communities) allow the beamforming capabilities in elevation as well as in azimuth to be exploited to maximize capacity.

When using LTE, an Evolved Packet Core (EPC) is also required, which is typically used for mobility and thus more complex than a fixed access core. This is an option for the Operator as a mobile operator with an existing EPC, but separating mobility and fixed traffic for this unique site was deemed more appropriate. A dedicated fixed core enables both a parallel fixed and mobile network (with or without shared provisioning and billing capabilities) as well as a core-as-a-service offering for other ISPs interested in using LTE but unwilling or unable to build their own LTE EPC. Another option is to use a small integrated LTE core-in-a-box, which could be co-located at the cell tower. Co-location of a small local core avoids the need to backhaul mobile traffic to a centralized core operation, and instead allows local provisioning and control, and direct interconnect to the internet and other local services. For this deployment, a Micro Core Network (MCN), a core-in-box solution capable of supporting a limited number of base stations, was used, although it was placed in the Operator's Central Office for convenience.

4.3 DEPLOYMENT COSTS

mMIMO equipment cost is higher due to higher complexity of both the RF antenna as well as the radio baseband processing. There is therefore some tradeoff between the increased cost of the equipment, and the higher coverage and capacity of the solution (which results in more connected customers, and so more revenue).

Deploying mMIMO does not differ significantly from the traditional macro tower deployments. From the administrative perspective (tower installation, backhaul connectivity, licenses, city approvals) the differences are minimal.

From tower work perspective, deploying with mMIMO versus traditional macro installation does not change significantly. One difference is that the antenna and RF sub-systems are integrated into a single unit, and so jumper cables are not required. It also results in a more compact solution, but a heavier one (can be on the order of 50 kg).

Commissioning and integration effort, as well as on-site support for remote integration remains largely the same. Design, planning and optimization activities typically require increased effort to reflect the extra complexity and effort needed for deploying mMIMO.

Backhaul cost is increased due to higher user capacity of the solution. One can expect to upgrade the backhaul circuits from IGE to IOGE in sites where maximum traffic volumes can be achieved.

The higher number of customers and traffic possible with mMIMO could provide enough revenue to cover the cost of the small, dedicated MCN. Since the MCN can support multiple base stations, adding more fixed sites to the MCN (either for the Operator's fixed service or as a service to 3rd parties), which should reduce the cost per user.

A percentage cost breakdown of all the components used for this market is shown in **Table 1**. The access and core equipment (mMIMO radios and MCN) make up the majority of the cost for this deployment. Integrating the new base station into the existing Operator mobility core would have reduced the overall (and percentage) cost for that item but may have increased some of the operational complexities as this is envisioned as a different service. Adding a new market in an area outside existing fixed access service could require a new employee to serve those new customers. If so, this is the next most expensive item after network equipment.

	Costs with new employee	Costs without new employee
Network Design	1.1%	1.3%
Backhaul Construction	3.5%	3.9%
Core Construction	39.0%	43.1%
Access Construction	39.0%	43.1%
Customer		
Acquisition/Marketing + Sales	0.3%	0.4%
Customer Installation	5.0%	5.6%
Provisioning	0.2%	0.2%
Billing (OSS/BSS)	0.2%	0.2%
Network Monitoring	0.2%	0.2%
New Employee	9.4%	N/A
Equipment		
Replacement/Maintenance	1.9%	2.1%

TABLE 1:

mMIMO Single-Market Cost Breakdown

5 BUSINESS MODEL

5.1 3RD PARTY ENGAGEMENT

These are several ways a massive MIMO LTE deployment could be made using operator assets but with a 3rd party to handle the customer-facing side of the equation. Because the spectrum, tower, and backhaul are owned by the operator, the 3rd party would have to lease or purchase all three for service. The operator could choose to put the partner's traffic on their mobility core, but it might make more sense to have a separate core used as-a-service. Building a core-as-a-service platform could enable multiple 3rd parties to tap into the operator's expertise in LTE without having to build and maintain their own core. In addition, a partnership of this sort could enable 3rd parties to use an MNO's high-capacity fallow spectrum in areas where the operator does not need it for their mobility network. Even an operator could use a separate core for a fixed service to fully separate its fixed and mobility businesses.

Three possible engagement models are shown in **Table 2**, the Operator-Only model (which was actually used in this market), as well as the Established ISP. An Established ISP is one with experience in delivering Internet services, with one or more markets deployed and earning revenue. The Established ISP has the full suite of resources required to build, operate, and maintain markets. While a Nascent ISP (an ISP in the process of forming) could be considered for a partnership, the cost complexity and complexity of the mMIMO LTE solution is probably more appropriate for a more experienced ISP to use. The analysis is performed to show how either an Operator or an Established ISP could expand into this market using a mMIMO solution hosted by the Operator.

	Engagement Models	
	Operator-Only	Established ISP
Network Design		
Backhaul		
Core		
Access		
Construction		
Backhaul		
Core		
Access		
Customer Acquisition		
Customer Equipment Installation		
Provisioning		
Billing (OSS/BSS)		
Maintenance + Operations		
Network Monitoring		
Equipment Replacement		

Operator Provides
Partner Provides
Both Provide

TABLE 2:

3rd Party Engagement
Model Options

There are a variety of ways that Operators and 3rd parties could split responsibilities; likely options have been selected and modeled. The Established ISP is likely capable of contributing to the design and construction of the access network, though the Operator may prefer to do all the work on its towers. The Established ISP would support access design by targeting specific consumers as shown in Figure 1 and could hire a tower crew (approved by the Operator) to perform macro tower installation. In this scenario, the Established ISP would lease the Operator's spectrum and use the Operator's core-as-a-service offering. This results in the Operator supporting the Established ISP with provisioning and by performing some level of the network monitoring and equipment replacement services (particularly for backhaul and core). The Established ISP solely owns customer acquisition, customer equipment installation and billing.

5.2 PAYBACK PERIOD

The decision to use mMIMO or simpler technologies (such as 4T4R or 8T8R) needs to take into account the density of consumers in the target coverage area and the expectations for the number of consumers that would sign up for service. The complexity, and higher cost, of mMIMO deployment is appropriate when the extra capacity that mMIMO offers is needed. This means that it is suited for scenarios where there are more households located in the target coverage area (i.e. a higher household density per square mile) and/or where the data rate consumption levels are higher (e.g. a 100/10 service versus a 25/3 service). Where a simpler technology would provide sufficient capacity for the coverage area, this is likely to lead to a lower cost solution. In other words, the variety of 'tools in the toolkit' that LTE technology offers allows some tuning of solutions to optimize the business case to cover different locations.

While the example in **Figure 1** only shows 20 users, there are more than 1300 households and businesses within 4 miles of the Operator's tower. While the mMIMO site cannot reasonably support all 1300 potential consumers, especially with the desired 100/10 Mbps data rates, it can reasonably support at least 10% of those consumers at a sustained rate of 10/1 Mbps simultaneously. More customers (more revenue) means a shorter payback period.

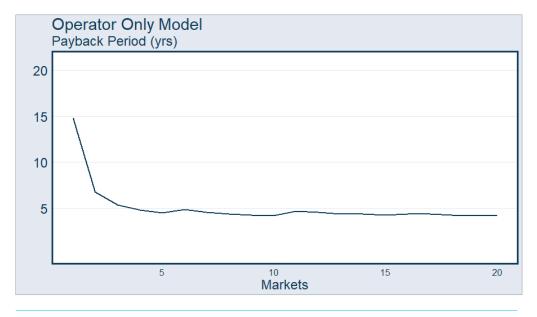


FIGURE 3:
Operator-Only Model, Payback Period vs. Number of Markets

The upfront costs as illustrated in **Table 1** (with the cost of an additional employee) produces an unacceptably long payback period for the Operator-only model for a single market (nearly 15 years) using a market average per-consumer cost and ~150 served consumers. The payback period could be improved by increasing revenue per consumer and degrading service levels, or by spreading costs over a number of markets, as shown in **Figure 3**. The main costs that are impacted by this model are the core (the MCN is intended to serve multiple base stations) and employee costs (a single employee could reasonably support a number of rural markets, if they are within an hour or so of each other). Sufficient scale can be achieved by building at least four markets, improving the payback period to 5 years.

A snapshot of revenue versus number of markets at the 5-year mark is shown in **Figure 4**. Note notches in the cost curve where additional core hardware and personnel are needed as additional



FIGURE 4:
Operator-Only Model, 5-year Revenue vs. Number of Markets

Figure 5 illustrates how the payback period can change for the Operator when enabling Established ISPs to use mMIMO. Figure 5 uses the shared cost approach as indicated in Table 2 and the same per-consumer revenue and served consumer assumptions as in Figure 3 along with typical fixed fees paid to the Operator for backhaul and monitoring and maintenance services. The result is a fixed per-market payback period for the Established ISPs and an improved payback period for the Operator for the first few markets supported. However, as the total number of markets increases, the Operator's payback period does not improve. Through the shared model, the per-market cost is reduced for the Operator, but the Operator's per-market revenue is also reduced. The Operator's revenue is now based on a single customer, the ISP, while the ISP's revenue is still based on the number of customers. The payback period for the Operator can be reduced significantly by increasing the fees charged to the Established ISP or using a per-consumer shared revenue approach. Doubling the fees paid by the Established ISP cuts the Operator payback period in half while still enabling the Established ISP payback period to remain at or around 3 years.

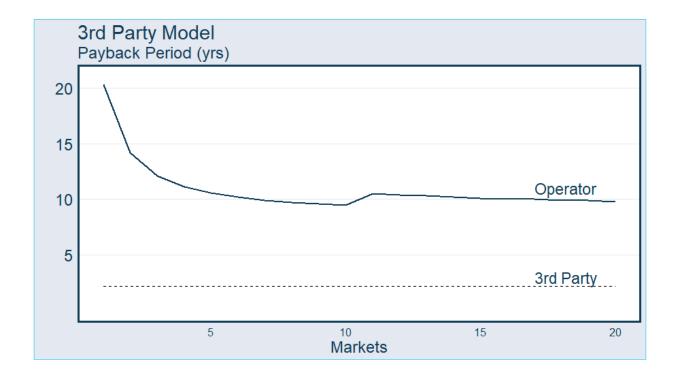


FIGURE 5:

3rd Party Model, Operator and Established ISP Payback Period vs. Number of Markets

6 CONCLUSION

The LTE Band 41 massive MIMO macro fixed solution used in a mixed rural environment is shown in Figure 6. Both the spectrum properties and advanced antenna technology enables high-throughput and capacity service [3] to LOS and NLOS consumers in small towns as well as scattered houses up to 4 miles away from the macro tower. Fiber deployments to even a fraction of the consumers would have been cost prohibitive, while micro-cellular deployments and unlicensed spectrum technologies would have proved technically challenging from the single macro tower used.

Due to the Operator's expertise and existing resources, an Operator-only business model is logical especially if the Operator can re-use resources such as towers, backhaul, existing core and personnel. While the high cost of mMIMO equipment and a new fixed core along with additional personnel cannot reasonably be supported by a single fixed rural market deployment, spreading some of those costs over at least 5 markets looks to provide a more viable payback period, assuming a reasonable consumer uptake.

Sharing the cost and work with a customer-facing 3rd party, such as an Established ISP, however, while providing a reasonable payback period for the 3rd party, does not significantly improve the Operator payback period even when multiple markets are supported without a significant increase in cost to the 3rd party. Providing support as-a-service along with access to Operator resources enables the 3rd party to use high-capacity mMIMO equipment that the 3rd party likely could not or would not use on their own.

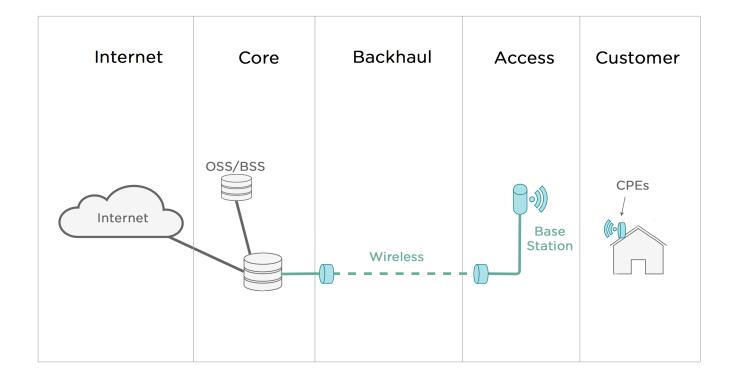


FIGURE 6: Broadband Connectivity Solution Diagram

For an area with many fewer potential consumers, a more cost-effective solution is typically used, although it would mean sacrificing capacity, and likely coverage. This is the trade-off that rural providers make in order to provide service.

Even with the more costly solution, terrain obstructs the macro wireless service at one potential consumer location, which was not ultimately connectable. Even more strenuous terrain would cause even more propagation issues and drive up the cost to serve more consumers. This also demonstrates a principle most often noticeable in rural areas (though also seen in urban mobility models as well); serving the last ~10-20% of consumers in an area is much harder and more costly than serving the first 80-90%. Although mMIMO proves itself to be another useful technology tool in serving rural broadband, there is still work to be done to make it a viable business solution for widespread Operator and ISP use.

As seen in Section 4.3, decreasing costs for access and core hardware and customer installation would reduce the overall cost of the solution. Rural broadband grants (public or private) to offset the cost of hardware would significantly reduce payback periods, especially for the Established ISP. How automation or optimization can help reduce costs in various areas is to be explored.

7 REFERENCES

- [1] "Broadband Technology Options," C Spire Rural Broadband Consortium white paper, August 2019, https://www.cspire.com/resources/docs/rural/CS_RuralBroadband_BroadbandTechnologyOptions_TechPaper_201908_v2.pdf.
- [2] "Case Study: Nascent ISP Business Model LEO Satellite Backhaul," C Spire Rural Broadband Consortium case study, October 2020, https://www.cspire.com/resources/docs/rural/CS_RuralBroadband_CaseStudy2.pdf.
- [3] https://www.nokia.com/networks/solutions/massive-mimo/#features-and-benefits

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