Making Private 5G Cost Effective

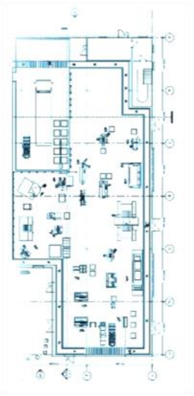
September 2022

Setting up a private wireless network for basic connectivity is becoming fairly routine. In the United States, a CBRS[1] network can now be set up in either "general" or "priority" access mode. In many enterprises, CBRS will be the perfect solution, providing IoT connectivity, and a simple way to connect push-to-talk handsets, broadband access, and advanced devices like automated ground vehicles.

But what happens when the enterprise needs more capacity? Priority licenses in the CBRS band use between 10 MHz and 40 MHz bandwidth[2]. Assuming the small cell uses the full 40 MHz channel, each small cell can support about 104 Mbps average (160 Mbps+ peak) in everyday operations. Plenty for voice communications and most basic IoT applications.

In the case of enterprises with heavy video analytics, however, a single location can drive demand in the range of a few Gbps, not Mbps. Scaling up in CBRS would be painful, with the deployment of large numbers of small cells…so let's look at the alternatives.

Cost Comparisons



To illustrate the costs involved, we examine two case study scenarios. In both cases, we want to equip a 40,000 square foot factory space with a private wireless network.

In **Scenario #1,** we have 30 robotic welding machines. Each robot uses two 8K resolution video cameras to control the welding tool for high quality in real time. This application calls for about 40 Mbps per camera, or 2.4 Gbps total capacity.

In **Scenario #2,** we have the same factory with only three robots instead of 30 robots. Everything else is the same, so that we can understand how capacity influences the cost picture.

Our choices include:

- **A CBRS-based private network based on small cells.** In this case, a private network can be set up by a mobile operator or by an independent system integrator. Up to 40 MHz of spectrum can be available on a priority basis, or about 80 MHz on a 'general availability' mode which is shared with other users.
- **A DAS system.** A Distributed Antenna System uses a signal source provided by the mobile operator and has the advantage of using multiple bands or even multiple operators to provide more capacity. DAS has been heavily used in stadiums for the past 20 years.

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[1] The Citizens Band Radio System: 3.55 to 3.7 GHz in the USA.

[2] Priority Access Licenses: In the USA, an enterprise can pay a license fee to have priority access to spectrum.

- **A millimeter-wave network.** In this case, a private network can be implemented by a mobile operator, or in some countries using a privately licensed mm-wave band. Because each mm-wave gNodeB has very high capacity, repeaters can be used to fill in coverage gaps.

Note that we also considered Wi-Fi networks. Almost every enterprise has a Wi-Fi network, and the wide bandwidth possible in the 5-6 GHz bands can be useful for some applications. However, for critical industrial operations where any hiccup will cause quality problems in the product, we see a strong preference for licensed-band radios now. Wi-Fi will be used in the factory for human broadband use and non-critical IoT devices like asset tracking. But the critical machines will run on either wires or licensed wireless.

The High-Capacity Scenario

In our high-capacity scenario, the CBRS private network requires 20 small cells to reach the required capacity, and may require some fine-tuning of power levels, antenna locations, and channel parameters, as all 20 small cells are sharing the same 40 MHz radio band.

The DAS network has the advantage of using multiple bands, and with one American operator a DAS system could incorporate about 120 MHz of spectrum. In this case, roughly 7 DAS sectors would be required through the facility, as each DAS sector would support about 310 Mbps.

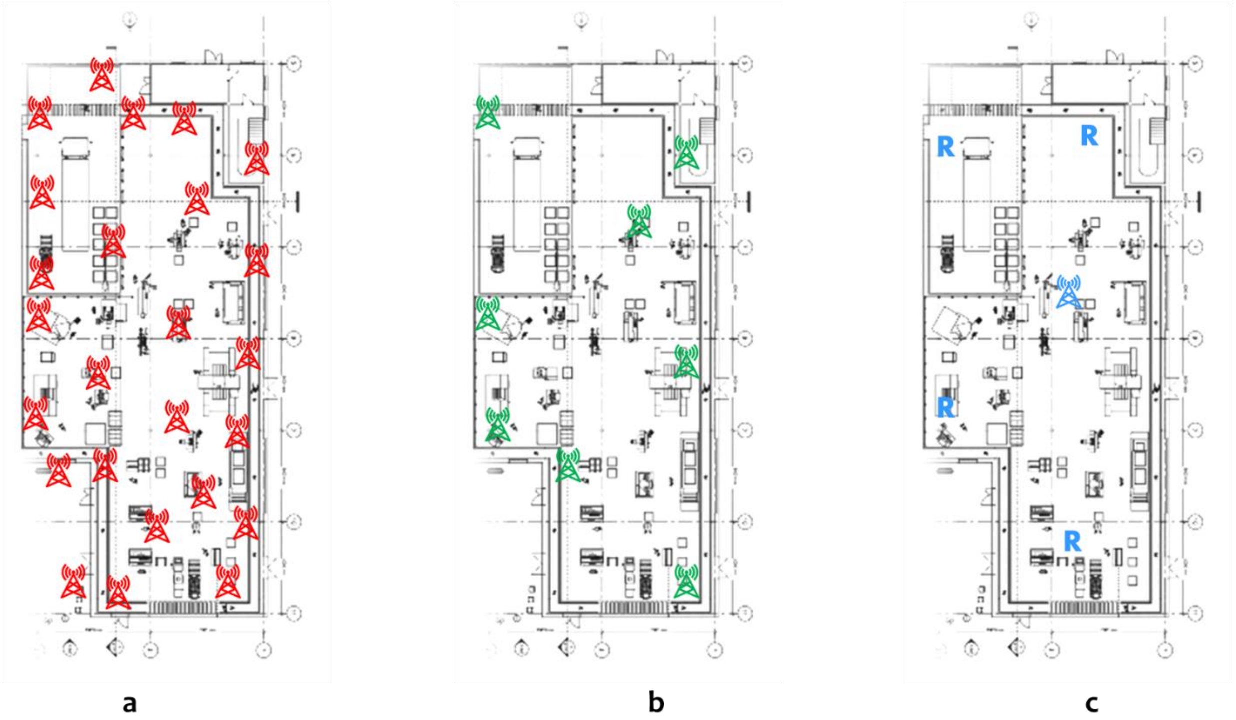
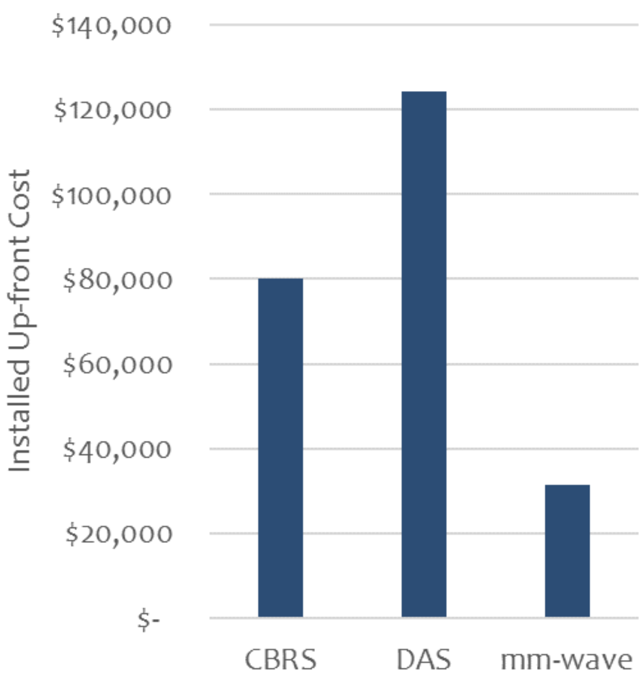


Figure 1 Layout of a) CBRS nodes; b) DAS sectors; and c) Millimeter wave gNodeB and repeaters

	CBRS	DAS	mm-wave
RF Bandwidth (MHz)	40	120	800
Capacity per Radio (Mbps)	104	312	3600
Radios required for capacity	19.2	6.4	0.6
Coverage per Radio (sq ft)	20000	20000	8000
Radios required for coverage	2	2	5
Actual Radios installed	**20**	**7**	**5**

Figure 2 Number of gNodeB units/sectors required for each architecture considered

A millimeter-wave network would meet the capacity challenge more easily, with a single gNodeB unit providing about 3.6 Gbps of capacity. In the mm-wave case, the deployment would focus on coverage, spreading the signal through the area instead of trying to minimize power and re-use frequencies in separate zones. One gNodeB radio would cover roughly 8,000 square feet adequately, so in this case we calculated the cost using a single gNB and four repeaters.



A factory with 30 robots saves 60% by choosing a mm-wave private network over CBRS.

Figure 3 Cost comparison for high-capacity scenario

Looking closely at the details, we see that the millimeter wave network saves money because the number of gNodeB units is low, resulting in a smaller number of fiber runs and simplifying the installation. One bit of complexity costs some money in the mm-wave case: We must include a low-band 5G anchor network, as today's state of the art demands a low-band anchor for high-reliability mm-wave operation. But in our factory example, this simply means that we add a CBRS radio to two of our five mm-wave radio nodes, and the added cost is only about $6,000 total (an additional fiber and two CBRS radios at $2500 each).

	CBRS	DAS	mm-wave
Cost per Radio	$ 2,500	$ 250	$ 20,000
Cost for DAS head end		$ 6,000	
Cost for DAS sources		$ 10,000	
Cost per mm-wave repeater			$ 500
Cost for low-band anchor radios			$ 5,000
Fibers installed	20	7	2
Cost per Fiber	$ 1,000	$ 1,000	$ 1,000
Electrician installation cost	$ 500	$ 500	$ 500
Total Up-front cost	**$ 80,000**	**$ 124,250**	**$ 31,500**

Figure 4 CAPEX cost comparison for high-capacity factory scenario

The Low-Capacity Scenario

In our second scenario, only three robots are required on the same manufacturing floor. In this case, there's no need to deploy large numbers of small cells, so the 5G network cost drops dramatically. In fact, the CBRS network can be roughly half of the cost of the mm-wave network due to the superior coverage of the CBRS small cells.

DAS is the most expensive alternative in all cases that we studied, due to costs for signal sources, head end equipment, and multiple fiber runs.

Note that in these two scenarios we consider only the up-front cost of installing the equipment. Several business models are possible for the in-building network, ranging from a managed service from a mobile operator to a privately installed and managed network, where the enterprise takes care of everything. For simplicity and clarity, our case study comparison simply looks at the network equipment itself and clearly demonstrates the raw cost of the equipment and its installation.

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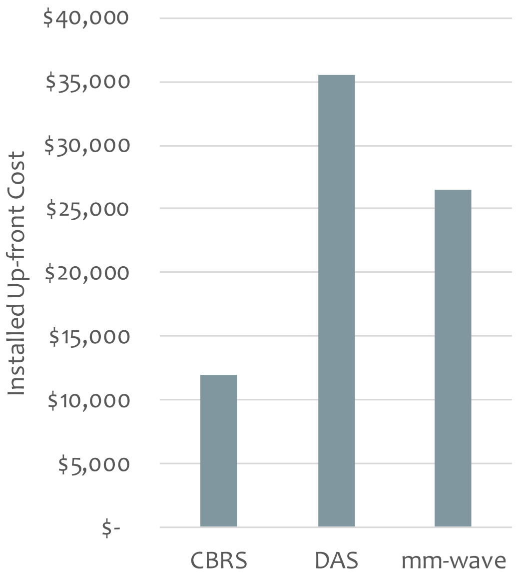

Figure 5 Cost comparisons for low-capacity scenario

In comparing our two scenarios, we see that the best choice of technology can depend directly on the level of capacity needed. In the low-capacity case, a simple CBRS network is best. But in the high-capacity factory case, a millimeter-wave network can be much cheaper.

You may ask: How is this possible? Millimeter wave small cells are much more expensive than CBRS small cells. So you might think that mm-wave networks are always more expensive than low-band networks.

In our case study and many other real-world scenarios that require high capacity, millimeter wave can be cheaper to implement for a simple reason: The high-capacity fiber deployment can be implemented in one place, and the rest of the deployment can use very simple repeaters to spread the capacity throughout the building. Using only the narrow radio band in the sub-6 GHz range leads to deployment of far higher numbers of small cells.

Even Higher Capacity

We've analyzed our two scenarios in terms of satisfying the capacity requirements of specific machines. But most projects are designed to include future capacity as well. If we have 30 robots today, we can implement a private wireless network to connect them, but we need to be sure that the network is scalable. Considering the CBRS and DAS options, scaling up from 2.4 Gbps to 5 Gbps of capacity would result in ridiculous numbers of radios in a small space. In fact, such extreme density of small cells would be unlikely to work at all.

On the other hand, with the millimeter wave network, to double the capacity in the factory we could simply replace one of the repeater nodes with a gNodeB. This makes future capacity enhancement simple and straightforward.

In the enterprise markets, we expect several scenarios to result in growing traffic demand over time:

- Factories using video analytics: resolution will increase over time
- Broadband usage by human employees;
- Videoconferencing is now standard in many factories;
- Medical/healthcare facilities should experience huge growth in bandwidth requirements; and
- Automated ground vehicles and other second-tier IoT devices will be added for greater efficiency in physical work.

Other Advantages of mm-wave in private networks

Millimeter wave networks are known for their difficulties in terms of signal attenuation, penetration through walls, and other propagation problems. For indoor enterprise use, these factors are not drawbacks….in fact, they are very positive attributes.

Lack of penetration through walls means that mm-wave bands can be used indoors without interfering with the mobile network outdoors. Many mobile operators are reluctant to implement private networks on their licensed sub-6 GHz bands, for fear of causing interference on the street outside. This concern is greatly reduced for mm-wave signals, which can fill the indoor space without significant leakage into the outdoor environment.

> *In a high-density indoor application, the 'negatives' of mm-wave become 'positives'.*

Attenuation of the high-frequency signals can be an advantage in setting up multiple sectors inside a building. In our case study, we calculated that the enterprise would use one mm-wave gNodeB and four repeaters, to spread the radio channel throughout the building. In an industrial building, interior walls can become an excellent boundary between the coverage zones of each repeater, helping to avoid any feedback loops or other distortions. Note that low-band radios will require much more attention to detail in setting power levels and antenna direction, due to overlapping coverage areas.

> *Deploying mm-wave repeaters can be quicker than pulling fiber for dozens of small cells.*

Time to market can be a significant advantage here. Specifically, in our case study comparison, the mm-wave network required only a single fiber location, and the repeaters could be implemented on various walls of the building using AC power only. That's much simpler than a low-band approach with as many as 23 fiber runs.   We expect private mm-wave networks to be implemented in hours, not days or weeks.

Finally, the wide bandwidth of the radio channel means that each robot can use different resource blocks. In cellular systems, high capacity depends on frequency re-use, and in a high-density environment such as our factory example, the radio frequency-and-time slots must be very carefully managed so that multiple small cells can re-use the same frequencies at the same time.   However, the mm-wave channel is wide enough that each robot can use different frequency and time slots, reducing the chances of interference. We expect this simple aspect to result in higher reliability for mm-wave networks in high-density applications, as well as a simpler deployment process.

> *The most difficult part of a high-density private network is frequency re-use. Fat radio channels make this easy.*

Figure 6 An indoor mm-wave repeater (courtesy of Movandi)

Conclusions

Many people think that mm-wave networks must be more expensive than sub-6 GHz, and in low-capacity applications they would be right. But automation of industrial processes is moving quickly toward very high-resolution video to enable Artificial Intelligence and Machine Learning to improve quality and productivity. We expect many real-world enterprise applications to emerge where mm-wave networks will be the best approach. Millimeter wave can offer the lowest cost, the quickest deployment, and the simplest RF planning in complex high-density scenarios.