MOBILE EXPERTS

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White Paper:

Cost Modeling of In-Building Wireless with OnGo

This white paper examines the total cost of deploying OnGo network for in-building wireless. It highlights CAPEX and OPEX costs and provides a comparative total cost of ownership over a five-year period of OnGo relative to today's standard Wi-Fi for private wireless networking and OnGo relative to DAS for an indoor cellular use case. The reference cost models highlighted in this report are specific to a 250k square foot office building and should not be construed as absolute figures.

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OnGo Benefits for In-Building Wireless

One of the many applications of OnGo technology is in solving the in-building wireless challenge. According to the U.S. Census, there are over 85 billion square feet of floor space across millions of commercial buildings in the United States. While mobile coverage in some of these indoor spaces is adequately served by "outside-in" coverage from nearby cell towers, one can find many venues with poor coverage and insufficient bandwidth indoors, resulting in poor user experience and customer complaints. This in-building wireless challenge is exacerbated by modern building materials like low-emissivity glass (Low-E) found in many modern buildings which prevent outdoor cell signals from penetrating inside buildings. Traditional in-building cellular technology like DAS provides a good neutral-host solution, but its high cost is out of reach for most mid-size or smaller properties. Wi-Fi offers a low-cost in-building wireless option, but voice communication is not seamless for many users. Here, OnGo offers a new in-building wireless solution that promises reliable and secure connectivity for private LTE/IoT applications like building automation in the near term, and seamless LTE and 5G mobility, in collaboration with operator support, at a more affordable cost.

Value of Mobile Wireless

Seamless wireless connectivity can have a big economic impact on enterprises in terms of customer satisfaction, worker productivity, and property asset value enhancement. Workers and consumers expect "always-on" wireless connectivity whether they are working in an office building or shopping at a mall. Providing "connected spaces" is becoming a key focus area for property owners and enterprises to attract and retain tenants and workers. While many venues already have Wi-Fi for data connection, many feel that indoor cellular connectivity is required to provide seamless wireless experience and leverage private LTE for smart building operations with expanding IoT sensors. We hear anecdotal evidence of good in-building wireless correlating to tenant acquisition and retention. Our analysis shows that in-building mobile coverage benefits enterprises more than it benefits operators, and OnGo offers an affordable cellular in-building and private LTE alternative for many building owners and enterprises.

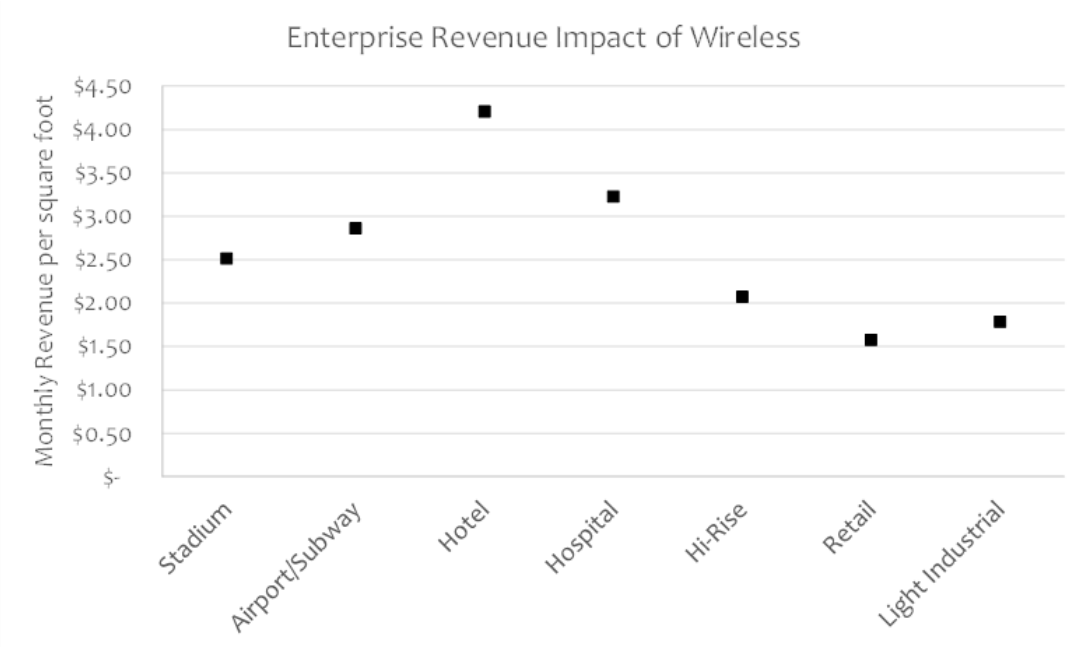


Figure 1. Value of Mobile Wireless to Enterprises[1]

Case Study: Mid-size Multi-Tenant Office Building

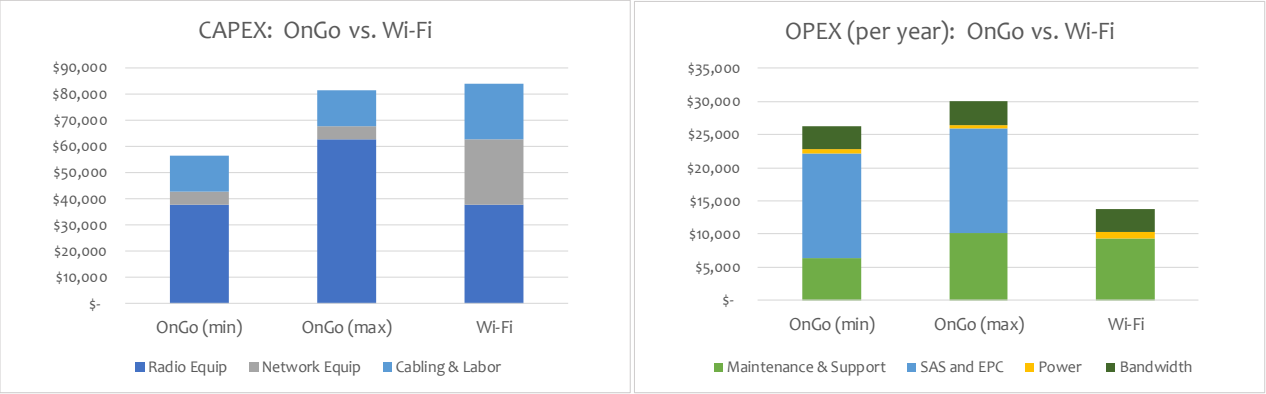
According to the US Census, there are about 9,000 high-rise commercial buildings (with ten or more floors) with over 200k square feet of floor space. While major public venues like stadiums and airports have DAS systems to provide seamless cellular connection, many smaller and less-public buildings lack robust cellular connectivity indoors. Many of these are multi-tenant office buildings where users bring their own device to talk, email, or stream videos. This "bring your own device" (BYOD) trend makes the in-building challenge even more difficult as the in-building wireless solution must support multiple operators to target the broadest user base at affordable costs. This "dual mandate" – to offer multi-operator cellular connectivity and keeping the cost low – makes this enterprise segment particularly challenging.

In this paper, we analyze the total cost of ownership (TCO) to build and operate a "greenfield" in-building wireless network with OnGo, Wi-Fi, and DAS for a 250,000 square foot, multi-tenant office building. For a "like-for-like" comparison, we first compare OnGo and Wi-Fi for a private wireless networking (private LTE/IoT) use case. We then compare OnGo and DAS for the indoor cellular use case.

[1] Mobile Experts 2016 *Enterprise Mobile Infrastructure* report

Private Wireless Networking Use Case -- OnGo and Wi-Fi Cost Comparison

Private wireless networking provides a good baseline use case to compare the cost structure of OnGo and Wi-Fi, a de-facto private wireless technology in most venues. As shown below, the one-time CAPEX cost – including radio equipment (Wi-Fi access points, OnGo radio units), networking equipment (PoE switch, controller, etc.), and cabling & miscellaneous items, and professional services (installation labor, design) – for OnGo is lower ($56k ~ $81k) than Wi-Fi ($84k). The main reason for this is that OnGo requires far fewer radio units than Wi-Fi to cover the same space – i.e., 25 OnGo radio units vs. 75 Wi-Fi access points.[2] In addition, the lower unit count of radios translates proportionally to lower network equipment and installation costs for OnGo. Although the unit cost of a Wi-Fi access point is significantly less than an OnGo indoor radio[3], there will be three times as many Wi-Fi access points as compared to OnGo. Hence, the net result is a slightly lower CAPEX cost for OnGo compared with Wi-Fi.



Source: Mobile Experts

Notes: 1) 25 OnGo radios vs. 75 Wi-Fi radios to cover a 250k sq. foot building; 2) OnGo (min) and OnGo (max) depict a range of OnGo radio average selling prices ($1500 ~ $2500 per OnGo indoor radio); 3) EPC "as a service" cost assumes 1000 IoT and 30 "over the top" voice communication users for the private LTE/IoT use case; 4) $200 per radio unit for PoE/switching costs; 5) roughly 5000 ft. of cabling run for the 250k sq. foot building and the number of radio units for installation labor cost

Figure 2. OnGo and Wi-Fi Cost Comparison for Private Wireless Networking Use Case for a 250k sq. foot office building

The lower CAPEX cost is offset by a higher OPEX cost, however, as the OnGo network requires SAS and Core EPC network (as a service) costs to manage IoT devices and VoIP users.[4] The key

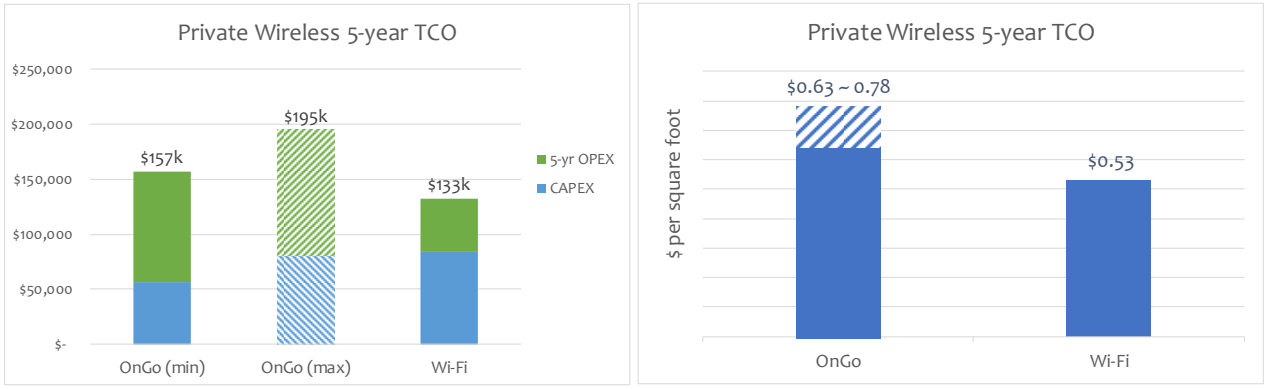
[2] About 10k sq. foot coverage per AP assumed for an OnGo radio unit based on 2x250mW output power operating at 3.5GHz. Using the Bain Wi-Fi cost estimator, over 3000 sq.ft. per Wi-Fi access point is estimated. Hence, an OnGo radio unit covers roughly three times as much area as a Wi-Fi access point. Actual number of radio access points will vary depending on floor layout, user density, building materials, and other factors.

[3] $500 Wi-Fi access point and $1500-2500 OnGo indoor radio unit average selling prices assumed. It should be noted that Wi-Fi (802.11ac) AP cost and performance assumed in the cost modeling.

[4] The EPC "as a service" cost is directly proportional to the number of devices and users managed by the Core EPC.

OPEX cost components -- including maintenance & support, power, and bandwidth – are pretty much the same across OnGo and Wi-Fi. The key differences in OPEX between OnGo and Wi-Fi are mostly related to SAS and Core EPC costs. Of the two, the Core EPC cost is expected to be a much bigger piece based on our assumed private wireless networking use case where 1000 IoT devices and 30 voice communication users are supported.[5] The total yearly OPEX cost for OnGo ($26k ~ $30k) is higher than Wi-Fi ($14k) arising from the SAS and Core EPC costs paid out "as a service."

Taking the one-time CAPEX plus yearly OPEX expenses as outlined above, the five-year TCO for a greenfield deployment with OnGo in our baseline 250,000 square foot office building comes to roughly $160k~195k vs. $135k with Wi-Fi in today's dollars. On a "$ per square foot" basis, OnGo is more costly ($0.63 ~ $0.78 per square foot) than Wi-Fi ($0.53 per square foot).



Source: Mobile Experts

Notes: 1) 5-year TCO calculation assumes 8% weighted average cost of capital; 2) The shaded figures/areas in the bar graphs represent range of OnGo (min) and OnGo (max) values reflecting a range of average selling prices of OnGo radios.

Figure 3. TCO of OnGo compared with Wi-Fi for Private Wireless Networking

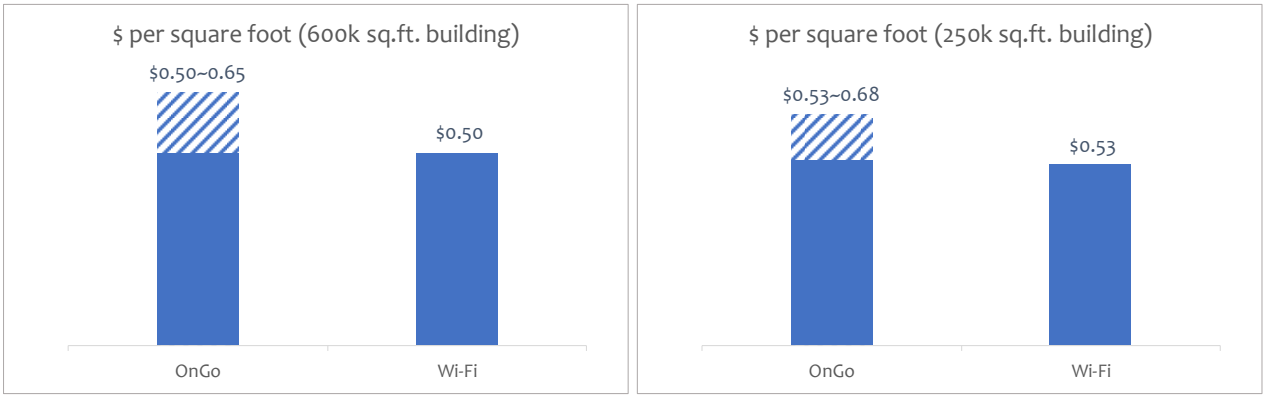
While Wi-Fi offers a lower cost indoor solution for general data connectivity use cases, the OnGo "premium" may be worthwhile for enterprise applications that require additional advantages inherent to LTE, including:

- Reliability - from interference-free wireless operation;
- Security - proven LTE security framework;
- Mobility – network coordinated "make before break" handover; and,
- Quality of Service performance – as a result of coordinated wireless access.

[5] Over $13.6k per year for Core EPC ($0.75/month per IoT device and $9.99/month per voice user based on Athonet BubbleCloud) and above $2k per year for SAS ($7/month per OnGo radio unit assumed)

In essence, the private OnGo network provides the building with a foundation for a commercial cellular wireless network.

It should be noted that OnGo can potentially reach similar TCO cost levels as Wi-Fi in certain scenarios that can take advantages of relative benefits of OnGo while minimizing its higher cost structure around EPC. For instance, as shown below, OnGo can reach similar TCO costs as Wi-Fi in larger venue or in scenarios that require less burdensome EPC usage scenarios.



Source: Mobile Experts

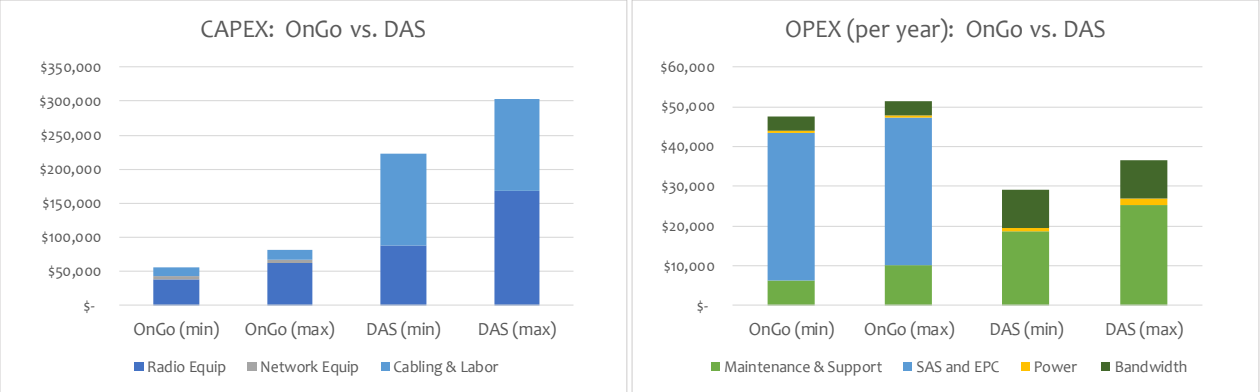
Notes: 1) 600k sq. foot building with 1000 IoT devices and 30 OTT voice subscribers modeled (the left graph); 2) 250k sq. foot building with 500 IoT devices and 15 OTT voice subscribers modeled (the right graph).

Figure 4. OnGo TCO can reach similar levels as Wi-Fi in larger venue (left) and in lower EPC usage (right) scenarios

In-building Cellular Use Case -- OnGo and DAS Cost Comparison

Another potential application of OnGo is solving the indoor cellular challenge. Many smaller venues require an indoor cellular solution but can't afford the relatively high cost and lengthy deployment cycle associated with multi-operator DAS installations. With operator support, OnGo has the potential to offer a multi-operator indoor cellular solution at a more affordable cost especially the upfront initial CAPEX cost and the cost associated with the significantly reduced time to enable cellular connectivity. As shown below, the one-time CAPEX cost – including radio equipment (OnGo radio units, DAS headend and remotes), networking equipment (PoE switch, controller for OnGo), and cabling & miscellaneous items, and professional services (installation labor, design) – for OnGo is significantly lower ($56k ~ $81k) than DAS ($222k ~ $300k). The main reason for the dramatic cost difference is the higher costs associated with DAS radio equipment, cabling (i.e., fiber and coaxial cabling for DAS vs. IT-centric structured cabling for OnGo), and significantly higher labor costs associated with DAS installations that require more involved cellular RF design and more complex fiber and coaxial cabling runs. In contrast, OnGo network installation mirrors the IT-centric model akin to Wi-Fi

installation involving simplified ethernet cabling runs and AP installations. These factors contribute to the one-time CAPEX cost for DAS that is almost four times that of OnGo.



Source: Mobile Experts

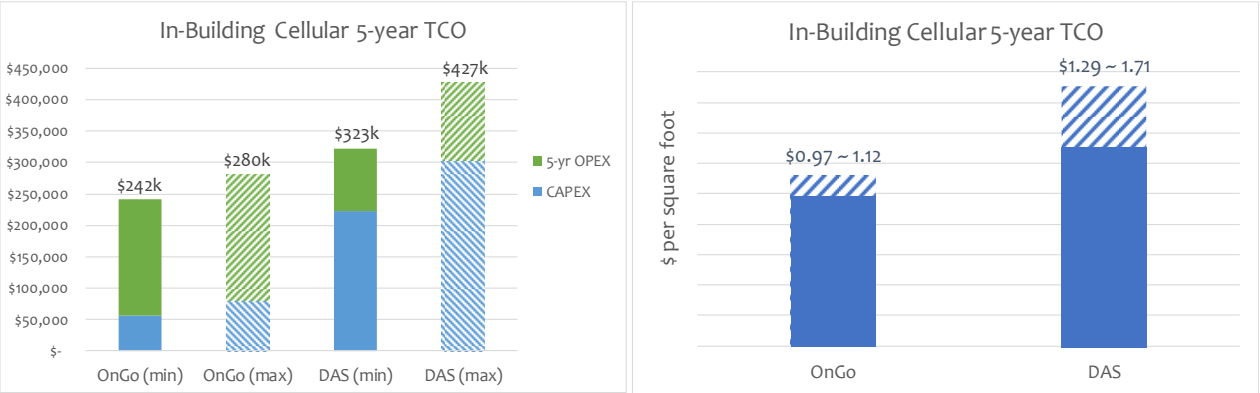
Notes: 1) 25 OnGo radios vs. 8 dual-band, 2W DAS remote units to cover a 250k sq. foot building; 2) DAS (min) case assumes that operators pay for signal source vs. DAS (max) case assumes that an enterprise directly funds small cell signal source for three operators ($30k per operator times three); 3) EPC cloud service cost assumes a discount volume discount for a neutral host provider with millions of subscribers aggregated across multiple buildings or areas; 4) $200 per radio unit for PoE/switching costs for OnGo; 5) roughly 5000 ft. of cabling run for the 250k sq. foot building and the number of radio units for installation labor cost; 6) OPEX costs are yearly figures.

Figure 5. OnGo and DAS Cost Comparison for In-Building Cellular Use Case

The lower CAPEX cost of OnGo is offset by the higher OPEX costs associated with SAS and Core EPC. The Core EPC cost is by far the biggest yearly OPEX item. To provide carrier-grade mobility service, the Core EPC cost is likely high. Here, we assume that a neutral host provider with millions of subscribers aggregated across multiple buildings can negotiate a volume discount for the EPC cloud service cost.[6] Otherwise, the Core EPC cost for a single mid-size office building would be prohibitively high. This economy of scale is needed for a high-cost item like core EPC. The total yearly OPEX cost for OnGo is higher ($48k ~ $51k) than DAS ($30k ~ $37k) arising mostly from Core EPC cost for "carrier-grade" services. It should be noted here that in the OnGo case, the enterprise or neutral host bears the Core EPC cost, while in the DAS case, operators bear the cost for Core EPC.

For the in-building cellular use case, the five-year TCO for a greenfield deployment shows that OnGo can be a cheaper ($242k ~ $280k) alternative to DAS ($323k ~ $427k) -- even with the Core EPC cost paid for by the enterprise or neutral host provider. On a "$ per square foot" basis, OnGo can provide a more affordable indoor cellular option ($0.97 ~ $1.12 per square foot) than DAS ($1.29 ~ $1.71 per square foot).

[6] $35k yearly EPC service cost for ~1600 users in the 250k sq.ft. building. Alternatively, a neutral host provider can directly source EPC equipment (and amortize that CAPEX over time) and run the EPC service directly to lower the OPEX cost.



Source: Mobile Experts

Notes: 1) 5-year TCO calculation assumes 8% weighted average cost of capital; 2) The shaded figures/areas in the bar graphs represent range of OnGo (min) and OnGo (max) values reflecting a range of average selling prices of OnGo radios.

Figure 6. TCO of OnGo compared with DAS for In-Building Cellular

Even with the higher OPEX cost associated with SAS and Core EPC, OnGo can be an affordable alternative to DAS especially at smaller venues that require a lower up-front cost. While neutral host indoor cellular solutions like OnGo and DAS ultimately require interconnection to the operators' core networks, the lower upfront cost, the lower TCO, and faster deployment cycle[7] of OnGo make it an attractive indoor cellular option for smaller venues as compared to large stadium projects often associated with traditional DAS projects. Moreover, the OnGo network is an asset owned by the building that can be used as a private LTE network to support building infrastructure and IT needs and potentially provide a source of revenue for the building management or owner.

It's important to note that, in addition to the cost savings of OnGo compared with DAS, the business model can also be much simpler from the point of view of the enterprise. With DAS, an enterprise can be confused by the need to buy DAS equipment and three or four different signal sources. The logistics can be a challenging project to manage. However, with OnGo, the enterprise will simply buy a single product or service. The benefits of simplicity are not covered in the TCO calculations but will make a difference in real-world adoption decisions.

[7] OnGo deployment cycle for a 250k square foot building referenced in our analysis is expected to take about a month as compared to 6-18 months to secure a signal source for some DAS projects. Factoring productivity lost due to poor indoor cellular coverage, the total cost including TCO plus lost productivity for DAS can be more than twice that of OnGo.

Summary

The CBRS commercial launch is close at hand, and the in-building wireless market represents an opportunity for OnGo to provide an in-building wireless solution for many commercial buildings where traditional cellular solutions have been too costly for property owners and enterprises to invest in. Using a 250,000 square foot office building as a reference venue, we see that OnGo is generally higher cost than Wi-Fi but offers additional advantages brought by LTE, including reliability, security, mobility, and high-speed performance. Also, with operator support, OnGo can potentially bring a lower-cost and faster deployment model for indoor cellular solutions at many small and midsize venues. Comparing the economic impact of in-building wireless overall, the OnGo TCO costs, ranging from about $0.70 per sq. foot (for private LTE/IoT use case) to $1.05 per sq. foot (for indoor cellular use case), seem like a sound investment for over $2.00 per sq. foot revenue impact for the high-rise office building (Figure 1). Enterprises should consider OnGo as an addition to existing Wi-Fi deployment to enable additional private LTE services in the near term and lay a groundwork for public LTE and 5G services indoors for the future.