Dealing with Density:
The Move to Small-Cell Architectures

Ruckus Wireless | White Paper

Options and Long-Term Strategies for Mobile Operators Facing Exponential Growth in Data Traffic

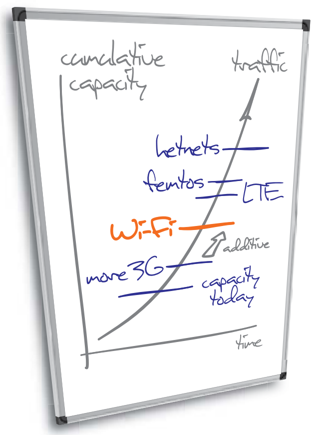
The expansion and evolution of cellular networks over the past decades has been astounding. Networks initially designed for voice traffic have grown to accommodate increasingly high data-traffic loads. This growth has long relied on a network of macro cells to provide a good balance of wireless coverage and capacity.

The fast uptake of mobile data services driven by smartphones, laptops, and more recently, tablets has accelerated data-traffic growth to the point that the macro cellular network is no longer sufficient to meet subscriber demand in many high-density settings all over the world. The introduction of LTE in the macro network will provide only limited and short-lived relief, as traffic is growing at a faster rate than the capacity increment it will yield.

While the macro network will continue to provide essential wide-area coverage and support for high-mobility users, operators have started to look at other solutions to increase capacity in high-traffic areas. Wi-Fi offload is the most widely and successfully adopted solution in areas where subscriber density and usage is high such as urban areas, and locations such as airports or stadiums. Operators are also exploring additional solutions, such as femto cells[1] to improve cellular coverage and capacity in residential areas, as well as small cell underlays to address high capacity density, and complement and strengthen their Wi-Fi and macro deployments.

1 In this paper we use the term femto cells to refer to cells used in residential or small business environments, serving a few subscribers who typically are responsible for the installation and backhaul of the femto cell and, as a result, they are not part of an operator-planned deployment. We define small cells as indoor or outdoor cells, typically deployed in dense topologies, close to the subscribers, and using a compact all-outdoor form factor, unlike macro cells, which usually have multiple sectors are located high above ground on assets like cell towers or rooftops, and are deployed to provide wide-area coverage.

Mobile operators can further improve network utilization by actively managing the traffic beyond the RAN within the core, using content caching, tiered pricing, and policy enforcement. These solutions do not increase capacity per se, but make data transmission more efficient, allowing operators to pack more content within the same network infrastructure.



While no single product or technology will alone accommodate the current and future increase in data traffic, many solutions, working in concert, can and should be considered. The challenge for mobile operators is not the decision of which solution to select, but how to best integrate multiple technologies within their networks, how to find the right balance to maximize their cumulative benefits, and how to leverage existing assets to facilitate the evolution of their networks.

Operators need a roadmap for a long-term and multi-step strategy to increase RAN capacity density (i.e., capacity per square kilometer) in high-traffic areas to meet the subscriber demand for data services. Wi-Fi for mobile data offload is one of the most efficient and economical means by which operators can immediately realize a steep increase in capacity — getting access to most desirable locations in high-traffic areas.

In the longer term mobile operators can gain a second capacity boost from LTE small cells, cutting costs and complexity by co-locating them with Wi-Fi access points, sharing site-lease agreements and backhaul. The integration of Wi-Fi and LTE small cells within the cellular core helps operators optimize network utilization across RATs through SON functionality — thus providing a further improvement in performance, and creating a seamless multi-RAT experience for their subscribers.

Moving Beyond the Macro Cellular Network

Macro cellular networks today typically provide coverage throughout a mobile operator's coverage area. Their capacity is adequate where the number of subscribers per cell site is relatively small. While high density areas account only for a small part of operators' footprint, they are of crucial importance. This is where subscribers are densely concentrated and where they use data services more extensively. The key challenge for mobile operators is to identify and correct capacity shortfalls in these high-traffic areas.

The conventional solution to increasing capacity has been to pack more cells within the same area. This approach has been effective for some time, but it suffers from diminishing returns as traffic grows, for a variety of reasons. High-traffic areas are usually in urban centers where deploying and operating equipment is more expensive, and where space can be difficult to secure. And as the density of macro cells increases, interference become more difficult to manage, with per-sector throughput declining as a result. Unless operators can secure additional spectrum, which is very difficult and costly in mature cellular markets, they reach a point where the capacity of the macro network approaches a saturation level. Then, any attempts at increasing capacity through conventional cell splitting become increasingly expensive and produce smaller marginal improvements.

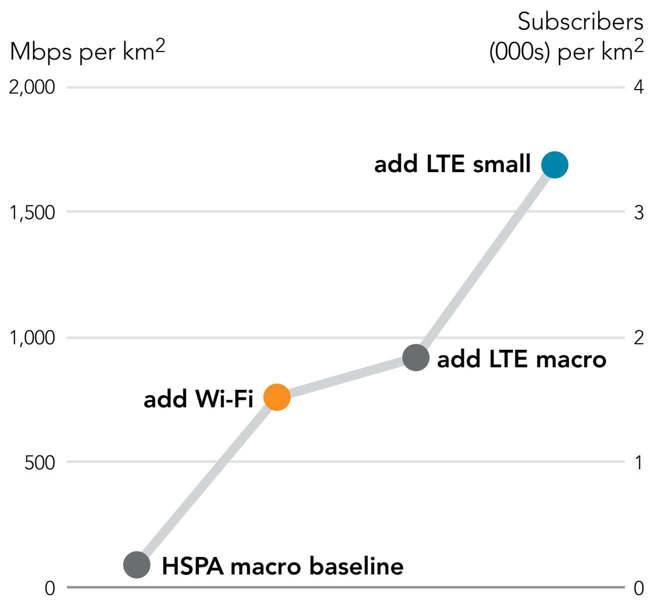
To deliver an increase in capacity of the magnitude sufficient to deal with exploding mobile Internet bandwidth demand, a new approach is needed. This approach is predicated on lower-power, shorter-range equipment such as Wi-Fi access points or 4G small cells installed closer to subscribers, in dense deployments. By limiting the range, the impact of interference is reduced while capacity density is increased. A single sector in a macro cell may have a comparable capacity to a Wi-Fi access point or a small cell, but it spreads it over a larger area, leading inevitably to lower capacity density.

An increasingly common approach being adopted by mobile operator s includes:

- Upgrading the 3G HSPA network where it makes technical and financial sense, but realizing that this does not provide the increase in capacity that is required in high-traffic areas.
- Building a Wi-Fi underlay network for mobile data offload to address the immediate need for additional capacity.
- Deploying a macro LTE network as spectrum holdings allow to establish coverage and to provide wide-area access for high-mobility users.
- Rolling out a small-cell LTE underlay network to provide additional capacity where needed, once LTE device adoption takes off. The small-cell LTE network complements the Wi-Fi network (and to a large extent it is expected to cover the same high-traffic areas) and the LTE macro network (mostly deployed for coverage and high-mobility access) to provide an additional capacity boost.

Figure 1 shows the relative contribution different network layers have with easing capacity density, measured in Mbps per square kilometer, for typical urban morphology cell range configurations and loaded-network spectral efficiencies. The corresponding axis on the right shows the number of active data users the network

FIGURE 1: Total RAN Capacity Density



Note: Based on typical spectrum allocations, loaded-network spectral efficiencies, and urban morphology deployment metrics.
Source: Operator and TEM benchmarking, Ruckus analysis.

can support per square km, assuming a traffic load of 0.5 mbps per subscriber.

Starting from a 3G HSPA baseline, Wi-Fi brings a more than seven-fold increase in capacity density. From the initial 200 subscribers, the combined network can support 1,500 active subscribers per square km. The further addition of the LTE macro layer only provides a further 17% increase in capacity, because of the inherently coverage-oriented nature of macro configurations. The next large increase in capacity density is provided the by final addition of LTE small cells, which provide over six times more incremental capacity density than the LTE macro layer, and adds a further 90% increase in overall network capacity.

Small Cells: Meeting the Challenges

Small cell deployments are one of the most popular long-term strategies of mobile operators worldwide because they provide the capacity boost needed in the near term, along with the flexibility and compact form factor needed for highly-localized deployments in high-traffic environments.

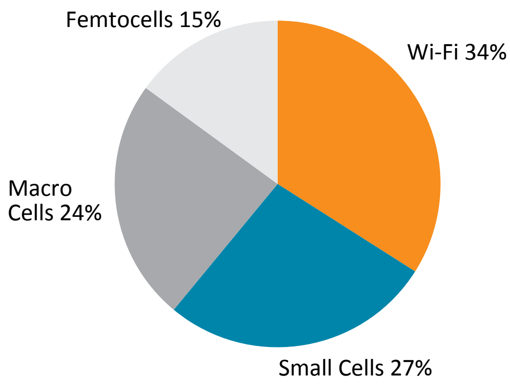
Yet, there are several challenges that need to be addressed when planning for a small cell underlay network to enable the operator to maximize the benefits of the new network and to keep costs under control. They include:

- **Securing mounting assets:** A high number of nodes is required and typically small cells are not mounted on the telecom assets like cell towers that operators are accustomed to managing or leasing. Mobile operators need to identify locations where installation and leases are affordable, and from which they can reach their subscribers. Because the range of small cells is short, the location for small cells — as well as Wi-Fi access points — is crucial to optimize network utilization. Locations for small cell installations typically include lampposts, interior and exterior building walls, or utility poles.
- **Increased opex:** While the equipment and installation costs are substantially lower for a single small cell than for a macro cells sector, the total cost of installing and maintaining a dense network of small cells can still be quite substantial because of the large number of locations.
- **Finding a flexible form factor:** Small cell locations sites frequently have strict limitations on equipment size, power availability and accessibility, and are difficult to secure. As a result, flexible, compact, and low-power form factors can greatly accelerate the rollout speed, and reduce installation and operating costs.
- **Boatloads of backhaul:** A backhaul solution that is well suited for dense urban environments and for close-to-the-ground equipment is required. While microwave point-to-point equipment costs have come down in recent years, it requires a line-of-sight (LOS) link with the connecting backhaul hub, a condition many small-cell locations will be unable to meet. Sub-6 GHz NLOS solutions using a point-to-multipoint architecture are better suited for dense underlays, but when using licensed spectrum, narrow bandwidth channels put strict limits on backhaul capacity, and most sub-6 GHz spectrum bands are expensive and frequently not available for licensing.
- **Integration with the cellular core:** The small cell underlay network must be fully integrated with the EPC and support SON to give the operator the ability to see and manage of user data traffic, support mobility, mitigate interference, and implement policy consistently across different RAT networks.

Wi-Fi Offload and Small Cells: A Complementary Approach

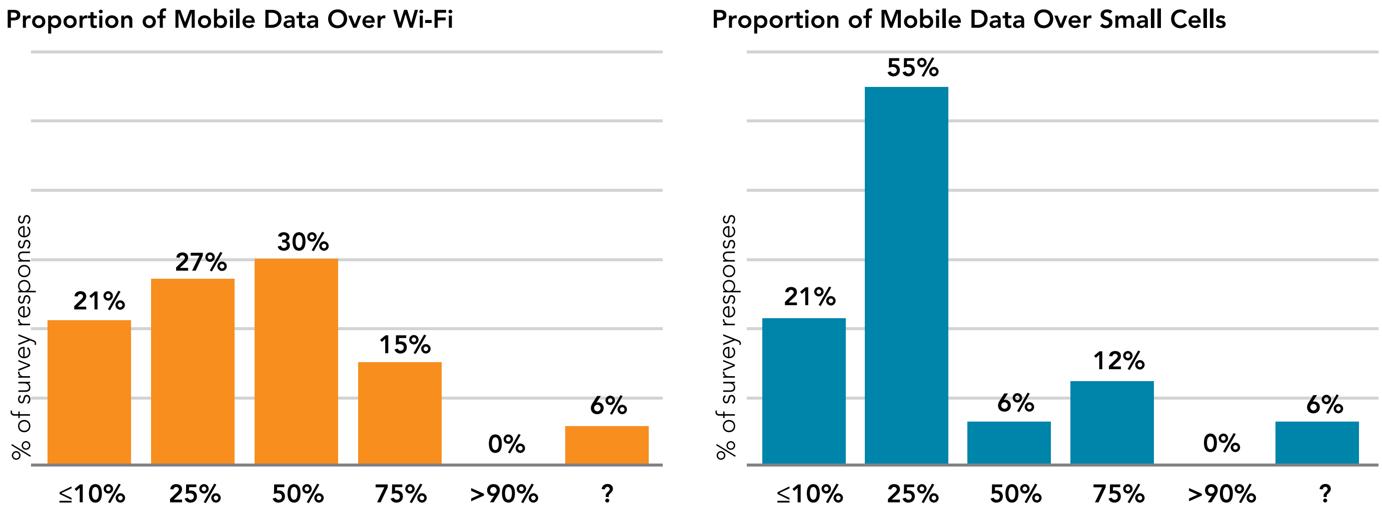
Most mobile operators no longer see Wi-Fi offload and small cells as competing solutions. They realize both are needed with each playing an important role within a multi-RAT, multi-layer cellular network — spanning from macro base stations at one end, to residential femto cells at the other.

FIGURE 2: Where Capacity Will Be Added



Source: Senza Fili Consulting

FIGURE 3: Perception of Mobile Data



Source: Senza Fili Consulting

A recent survey by Senza Fili Consulting of mobile wireless executives that focused on data services at mobile operators, vendors, and regulators shows that Wi-Fi offload and small cells are considered the most effective solutions in increasing capacity in the RAN. Over the next five years, Wi-Fi offload is expected to provide 34% of capacity increase, small cells 27% (Figure 2), with Wi-Fi having a corresponding stronger role in offloading traffic than small cells (Figure 3). This reflects the fact that Wi-Fi offload is aggressively being pursued by operators today, while small cell deployments are expected to pick up speed later after the LTE macro networks are in place. As a result, in five years, many operators will still be expanding the small-cell footprint and have not reaped all the capacity benefits to be gained from small cells.

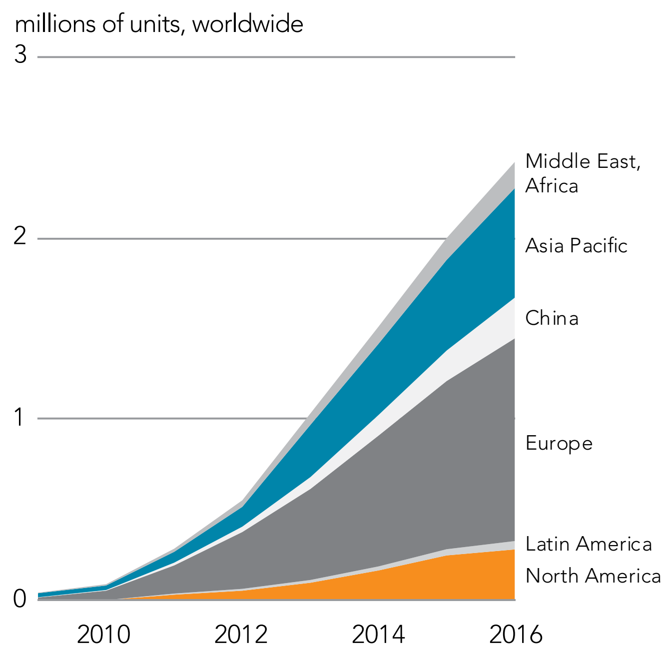
Another survey, conducted by the industry consultancy Mobile Experts through detailed interviews with more than 30 mobile operators' network and business planning teams, revealed the longer-term criticality of small cells to operator strategies. The Mobile Experts' forecast for low-power pico cells (their term for the small cells we're discussing here) was derived primarily from these operator interviews and shows clearly (see Figure 4) that operators expect to use these small-cell devices in very large numbers.

One or Two Networks?

Wi-Fi and LTE small cells will eventually become two network underlays that are largely overlapping and share many common elements. But should mobile operators keep the two networks separate, or integrate them within a multi-RAT network?

Operators may initially find it easier to keep their Wi-Fi offload network separate from their cellular network, and manage traffic and subscribers independently — diverting specific types of traffic, based on application, subscriber tier or other criteria, to different networks. This approach reduces the upfront efforts to roll out a Wi-Fi offload solution, but it precludes them from fully benefitting from the Wi-Fi infrastructure, especially in the long-term.

FIGURE 4: Low-Power Pico Cell Shipments



Source: Mobile Experts

Instead, mobile operators that choose to integrate Wi-Fi within the cellular network today can more effectively take advantage of the capacity increase that Wi-Fi brings by managing all traffic within a unified framework within the same core network, and present a consistent authentication and service interface across RATs to their subscribers. Furthermore, Wi-Fi and cellular integration will enable them to roll out LTE small cells more easily as a network upgrade by sharing network resources, such as locations and backhaul, with the Wi-Fi offload infrastructure (Table 1), rather than as a stand-alone network.

A Two-Phase Approach

Based on engagements with a number of mobile operators, Ruckus believes the best strategy to integrate Wi-Fi and small cells is centered on the two phases described in Table 2 which

TABLE 1

ADVANTAGES OF WI-FI INTEGRATION WITHIN THE CELLULAR RAN

Small cell equipment	Add-on module to Wi-Fi access points, or separate equipment unit with a very compact, low-power configuration
Locations	Small cells co-located with Wi-Fi access points. Site acquisition and permitting is required only during the initial Wi-Fi deployment
Backhaul	Integrated, shared backhaul
Operating costs	Partly shared (i.e., power, lease, maintenance)
Provisioning	Unified authentication, policies, billing, with enhanced security and SIM-based authentication available for Wi-Fi access
Subscriber experience	Full visibility in subscriber's QoE , consistent experience across RATs
Mobility support	Transparent mobility, roaming support
Traffic management	Flexible traffic forwarding architecture, that can be based on real-time traffic load, application, policy, subscriber tier. Mobile operators can choose to continue to direct best-effort traffic to the Wi-Fi network and reserve the LTE small cell networks for services that require more stringent QoS functionality, such as video streaming or VoIP, or for high-tier subscribers.
EPC	Standards-based, multi-access network architecture integrated in the mobile core
HetGen functionality	Implementation of SON features across cellular and Wi-Fi networks to optimize network performance across RATs
TCO	Highest increase in data traffic density with the lowest TCO

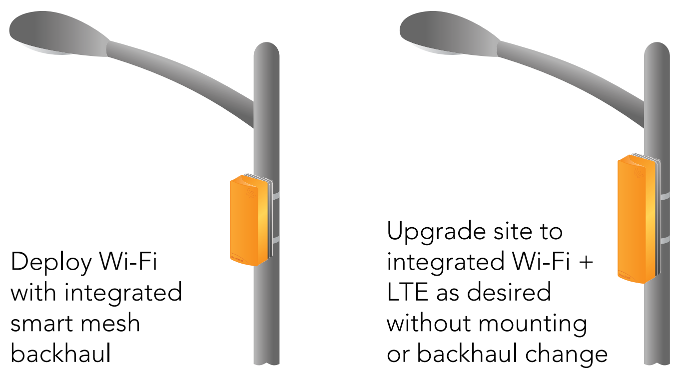
TABLE 2

A TWO-PHASE APPROACH FOR A UNIFIED WI-FI AND SMALL-CELL STRATEGY

PHASE 1: Deploy Wi-Fi Offload Today as Part of the Cellular RAN	PHASE 2: Add LTE Small Cells, Co-located with Wi-Fi Hotspots as a Network Upgrade, and Continue Ongoing Expansion of Wi-Fi Access Points and Continue Ongoing Expansion of Wi-Fi Access Points
Benefit: The Wi-Fi infrastructure offer operators capacity relief to their 3G infrastructure, by allowing them to route best-effort traffic through Wi-Fi.	**Benefit:** The second increase in capacity that LTE small cells deliver can be rapidly deployed leveraging the Wi-Fi existing infrastructure and related assets. Further capacity increase is to be obtained by expanding the network to new locations in which both Wi-Fi access points and LTE small cells are co-located.
Installation: High-traffic locations are identified for Wi-Fi IEEE 802.11n access points, permits and lease contracts arranged, and electricity and backhaul set up. The acquisition of key locations enables a land grab that establishes the future footprint of the LTE small cell network.	**Installation:** LTE small cells can be installed as an add-on unit to the Wi-Fi access point, without re-permitting and sharing the backhaul connection already in place. In a new location, both Wi-Fi and small cell equipment can be jointly installed, with the same installation costs and efforts required by the deployment of a single wireless interface.
Network management: The Wi-Fi network is fully integrated within the cellular core and managed as part of the RAN.	**Network management:** Integration of the LTE small cell and Wi-Fi networks within the EPC, and use of SON functionality through the use of a wireless services gateway gives operators maximum flexibility in directing traffic to desired network underlay, and powerful tools to optimize use of network resources and to mitigate interference.

includes a short-term capacity enhancement through Wi-Fi offload, within a robust long-term converged Wi-Fi and cellular strategy, during which both Wi-Fi and small cells continue to be deployed as needed to accommodate traffic growth. Small cells can be configured as an add-on module that will typically be deployed in an integrated package for ease of deployment and highest reliability in the field. (Figure 5)

FIGURE 5: Wi-Fi to LTE Deployment Transition Concept



Completing Phase 1: The Initial Wi-Fi Deployment

Ruckus' Wi-Fi offload solution offers mobile operators a complete Wi-Fi offload approach that is fully integrated with the cellular RAN, and that sets a solid foundation for an effortless, incremental deployment of LTE small cells. Ruckus' Wi-Fi offload solution points provide unrivaled radio performance and reliability even in the most dense and challenging urban environments, due to:

- **Patented adaptive antennas:** Innovative adaptive antenna technology, fully compliant with Wi-Fi industry standards, driving superior air interface performance and interference rejection in Wi-Fi access points.
- **High-capacity LOS and NLOS 5GHz Wi-Fi backhaul:** Easy-to-install, auto-forming, auto-optimizing, and self-healing NLOS backhaul to connect Wi-Fi access points using smart mesh 5 GHz backhaul that can be combined with wired Ethernet connections within the same mesh. Ruckus backhaul technology supports up to 400 mbps in LOS mode, and up to 100 mbps in NLOS mode.
- **Advanced Wi-Fi meshing techniques:** Network optimization with smart meshing, dynamic channel management, client load balancing, band steering, airtime fairness, and QoS managed at the access point level enabled by the Ruckus wireless services gateway (WSG) (Figure 6). Designed for dense deployments, the WSG is massively scalable, supporting up to 10,000 access points, 100,000 clients, and a throughput of 20 gbps per chassis.
- **Seamless integration with the cellular core:** The Ruckus WSG provides provisioning for SIM and non-SIM clients, authentication, security, mobility management, tunnel termination, transaction caching and Wi-Fi EMS. The WSG also supports the Wi-Fi Alliance Next-Generation Hotspot program (also known as Hostpot 2.0) and IEEE 802.11u, which makes interworking across networks and RAN interfaces seamless to the subscriber.

Fast adoption of Wi-Fi radio enhancements, starting with the IEEE 802.11n Wi-Fi radio interface, and a carrier-class subscriber experience even in the heavily-used and license-exempt 2.4 GHz and 5 GHz bands, especially notable in RF-challenging environments, set the Ruckus solution apart from the competition, and make it ideally suited for mobile operators.

Leveraging Wi-Fi for an Easy Upgrade to LTE Small Cells

Once a mobile operator has the Wi-Fi offload infrastructure in place, it has done most of the hard work to roll out LTE small cells (Figure 7). Thanks to its early Wi-Fi land grab, it has secured a network of permitted Wi-Fi access points and small cell sites, with power, backhaul, and lease agreements, ahead of its competitors without Wi-Fi offload. Access to small cell mounting real estate is crucial to keep installation and operation costs down, and to reduce deployment times. The Ruckus WSG provides the

FIGURE 6: Ruckus Wi-Fi mobile data offload solution

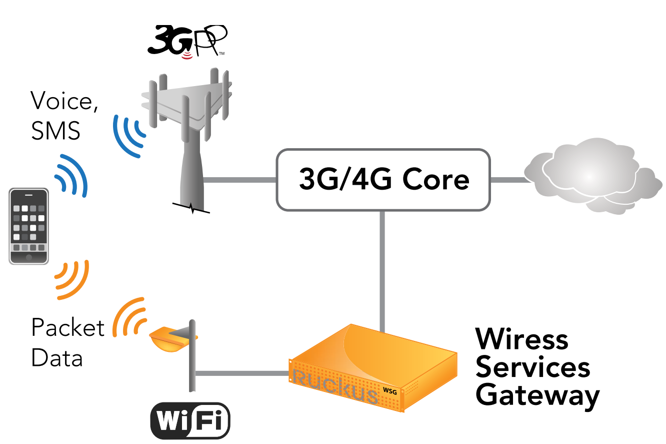
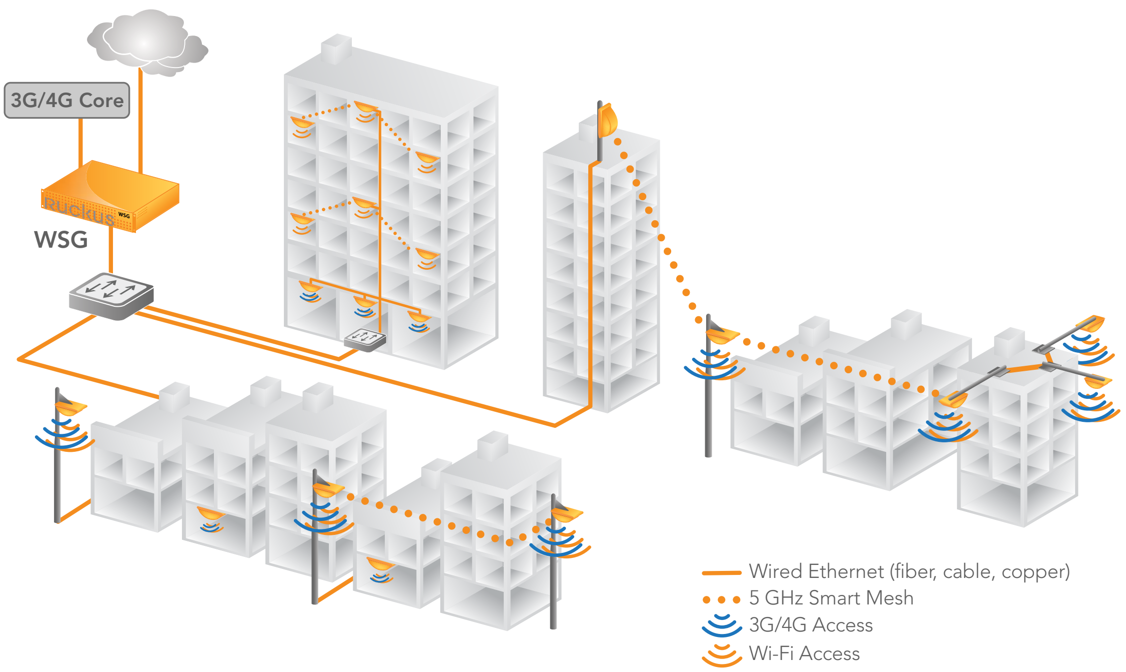


FIGURE 7: The Ruckus solution for a Wi-Fi and LTE small cell integrated network supported by Smart Mesh backhaul



foundation on which small cells and Wi-Fi access points can be jointly managed. The Smart Mesh backhaul network is ready to support LTE small cells along with the Wi-Fi access points.

To leverage the existing Wi-Fi offload infrastructure, small cells must have a sufficiently compact form factor to fit in Wi-Fi access point locations — they can be add-on modules or separate units — be easy to install (and replace), support SON functionality, and be fully integrated with the EPC that supports the LTE macro network.

The WSG establishes a multi-access network architecture by combining the functionality of a WLAN controller and a 3GPP WAG providing backhaul and system management, and supporting 3GPP interfaces.

Over the years, Ruckus has gained essential experience in building self-organizing Wi-Fi solutions that self-configure, self-optimize, and self-heal — well ahead of the development of licensed-spectrum SON and that target Wi-Fi license-exempt bands, which are far more challenging than cellular licensed bands. This early experience gives Ruckus a strong competitive and time-to-market advantage in adding robust support for standards-based SON for LTE small cells and SON-equivalent functionality for the Wi-Fi access points to the unified Wi-Fi offload and LTE small cell solutions.

SON functionality is particularly crucial to managing LTE small cells. The configuration and optimization of a network that includes a large number of small cells, compared to a traditional macro network, will quickly overwhelm traditional manual approaches to RAN management. Further, the real-time aspects of interference management, load balancing, and coverage shaping will also increase in complexity as the number of cells goes up, and as multiple integrated underlays coexist side-by-side.

Conclusions

The massive increase in data traffic is pushing mobile operator beyond the predominantly macro cellular architecture that has dominated the first decades of growth in mobile communications. While still necessary for coverage and support for high-mobility subscribers, the macro network cannot provide the desired increase in capacity, even when LTE is deployed.

To ensure the effective management of expected traffic loads and to increase capacity density within high-traffic urban areas, most mobile operators are deploying or plan to deploy underlay networks of Wi-Fi access points and 4G small cells. Small cells are much closer to subscribers with a smaller range and can provide higher capacity density than macro cells. Increasingly, Wi-Fi and LTE underlays will coexist, and both will play an essential role in the operators' long-term data strategy.

Not only can Wi-Fi and LTE operate side by side, but they crucially complement each other within an integrated deployment strategy, delivering the highest capacity increase afforded by next generation radio technology and spectrum availability, combined with the lowest TCO.

The initial deployment of an IEEE 802.11n Wi-Fi offload solution provides mobile operators with an immediate capacity increase, available to most data-centric devices already in the hands of their subscribers. But, equally importantly, the Wi-Fi infrastructure provides the foundation on which mobile operators can realize their longer-term data strategy, by establishing a network of sites that can be shared by Wi-Fi and LTE small cells. Once they decide to roll out LTE small cells, operators can simply add an LTE small module to their Wi-Fi access points – sharing lease costs and backhaul capacity.

The Ruckus solution goes well beyond enabling a Wi-Fi land-grab, providing a Wi-Fi offload solution with unrivaled radio performance, carrier-level scalability and flexible management options. Today, it gives operators powerful tools that will need to fully integrate the Wi-Fi and LTE underlays with the macro core, to optimize the utilization of network resources, and to provide to their subscriber a smooth, seamless access to their multi-RAT, multi-layer network.

Acronyms

3G	Third generation
3GPP	3rd Generation Partnership Project
4G	Fourth generation
AP	Access point
BSC	Base station controller
BTS	Base transceiver station
CoMP	Coordinated Multipoint
EMS	Element management system
eICIC	Intercell Interference Coordination
eNodeB	Enhanced NodeB [LTE base station]
eNB	eNodeB
EPC	Evolved packet core
GSM	Global System for Mobile Communications
GW	Gateway
HetGen	Heterogeneous network
HSPA	High-speed packet access
HSS	Home subscriber server
IEEE	Institute of Electrical and Electronics Engineers
N	N interface [connecting eNodeBs and OA&M]
S1	S1 interface [connecting eNodeBs and the EPC]
X2	X2 interface [connecting two eNodeBs]
LOS	Line of sight
LTE	Long term evolution
MME	Mobility management entity
NLOS	Non line of sight
NodeB	[3G base station]
NB	NodeB
OA&M	Operations, administration and maintenance
QoE	Quality of experience
QoS	Quality of service
RAN	Radio access network
RAT	Radio access technology
RF	Radio frequency
RNC	Radio network controller
SGSN	Serving general packet radio service (GPRS) support node
SIM	Subscriber identification module
SON	Self-organizing network
TCO	Total cost of ownership
UMTS	Universal Mobile Telecommunications System
VoIP	Voice over internet protocol
WAG	WLAN access gateway
WLAN	Wireless local area network
WSG	Wireless services gateway

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