



The evolution of Ultra-Dense Networks

Executive Summary

As traffic continues to grow, today's largely macro cell networks will evolve, becoming more tightly packed and eventually becoming ultra-dense. An ultra-dense network (UDN) is one with sites on every lamp post or with indoor sites placed within 10m of each other. By 2025 or 2030, Nokia expects UDNs to be covering most urban indoor and outdoor areas and providing cell edge data rates of 100 Mbps to everyone.

When deploying UDNs, operators face key challenges that must be addressed to be able to provide subscribers with top quality services while also minimizing the network's Total Cost of Ownership (TCO).

Controlling site and deployment costs

The first consideration in reducing TCO is to minimize site acquisition and deployment costs. Sites are often spread between many owners, each with their own rules. A 'menu' of pre-qualified sites helps to avoid a lengthy acquisition process, while discreet enclosures help gain local acceptance of small cells. As well as being unobtrusive, small cells that are light and truly 'all-in-one' can make installation much simpler and faster.

A further opportunity is to share sites with other operators. Such sites may be owned by municipalities or run by specialized site management companies.

Deployment costs can also be reduced by using standardized site designs that not only improve efficiency but also need fewer skilled staff. Clustering small cells for bulk deployment also cuts costs by allowing simultaneous planning and installation, while Intelligent Self-Organizing Network (iSON) capabilities allow configuration to be automated, enabling faster set up times.

TCO also depends on how easily power and backhaul transmission can be brought to the small cell site. The small cell use case and location will define the backhaul requirement and there are three options:

- Fixed backhaul, mainly fiber to support future bandwidth requirements
- Point to point: Line of Sight (LoS) and Near Line of Sight (NLOS) wireless transmission - each access point will have a microwave radio with a LOS or NLOS connection to the macro.
- Point to multipoint wireless transmission - a single backhaul connectivity point will serve multiple access points.

A specific backhaul solution may not always be viable, increasing TCO. Options 2 and 3 entail more planning, while option 1 depends on where the fiber access is located. As small cell populations increase, it will become a challenge to ensure the wireless link performance is not degraded by changes such as new buildings.

Minimizing operational expenses

Once deployed, the operator will need to keep operational expenses low. A key cost is energy consumption, which can be cut by using dormancy features (SON based) that can save significant amounts of power by shutting down carriers or switching off MIMO. Other energy reduction measures include optimizing sites based on HetNets which can lead to lower RF power on some macro sites; beamforming to improve efficiency by cutting interference; distributed systems with baseband pooling to improve resource use; and network modernization to replace legacy equipment with more efficient modern solutions.

An operator in a medium-sized country may have 8-10,000 base station sites, but as the network becomes denser, there may be more than 100,000 cells to manage. With this increase comes an exponential rise in network data. Yet the operator will need to keep operational expenses low using the same number of engineering staff. Solving this will involve analytics, extensive automation and redesigning tasks and processes to move from traditional reactive ('break then fix'), to proactive ('health checking') network maintenance.

Automation enables an operator to evolve to proactive and predictive approaches to network maintenance. Predictive software will use intelligent machine-learning algorithms to help spot anomalies that would otherwise remain unnoticed.

Dense LTE networks and multi-connectivity

As small cells become important for capacity and high data rate coverage, operators must decide how to integrate them into their wide area network. Wi-Fi data offload has been widely successful without tight integration, but LTE offers more options to integrate small cells and further multi-layer integration options become available with 5G. These can increase the benefit of having multiple radio layers and in particular the installed small cell layer.

Multi-connectivity is another vital technology that will support simultaneous access via LTE and later 5G networks, as well as aggregating Wi-Fi to those networks. A variety of ways to integrate the use of unlicensed spectrum has been developed by 3GPP:

- LTE Wi-Fi Interworking to enable the operator to control off and onloading and gain maximum benefit from its Wi-Fi assets.
- LTE Wi-Fi Aggregation (LWA): aggregating LTE and Wi-Fi spectrum and transmissions to create seamless interworking and higher data rates.
- Licensed Assisted Access (LAA): moving LTE to the unlicensed spectrum and aggregating it with licensed spectrum.

The focus for these unlicensed options is on the 5GHz band, which has a lot of bandwidth available.

If an operator has a large installed Wi-Fi access point base, then applying LWA may be less costly than using LAA for those areas. New areas can still use LAA, as LAA and Wi-Fi can readily coexist. While almost every device has Wi-Fi built in, LAA is expected to follow.

One advantage of LWA is that the Wi-Fi access point does not need to be co-located with the LTE small cell, as long as there is a good interface between them. The main advantage of LAA is the better performance, which is especially pronounced under high loads and it is easier to manage because the operator only needs to deal with one system, as everything is LTE based.

Evolving the RAN architecture

As inter-site distance reduces, site placement must follow building layouts and available space instead of being governed only by propagation and traffic conditions. In very dense networks, interference paths are complex and cell boundaries become less well planned. Hence, dense small cell networks require optimization. It is in such dense networks that coordination provides most value and RAN architecture choices start to be important. Establishing mesh X2 connectivity may not be practical to achieve high coordination performance - a lower cost solution is the Flexi Zone cluster.

A straightforward solution to improve performance within the small cell cluster and use performance enhancing features such as load balancing and coordinated scheduling is to establish fast communications between the small cells. As network density increases, it is more efficient to introduce the Flexi Zone controller in a common aggregation point that aggregates S1 and X2 connections and provides additional performance-enhancing features across the cluster. Nokia studies have shown that up to 30 percent lower TCO can be achieved for the small cell cluster.

With access to dedicated fiber or fast Gigabit Ethernet, a final option is to build a small cell Centralized RAN (C-RAN) with a single baseband pool that integrates all the small cell access points as low-power RRHs. For cases like stadiums where cabling is fairly easy, the small cell C-RAN architecture provides a TCO efficient solution with unparalleled capacity and end-user experience.

Dense networks and Cloud-based RAN

As networks become denser, cloud-based radio networks will be deployed to optimize performance, simplicity and TCO. This comes with smart centralization and virtualization of key components to reduce site and traffic routing costs while distributing other key components for unparalleled radio performance in terms of latency and spectral efficiency.

At the same time, operators will need to ensure consistent and next generation of service experience regardless of the point of the access, using multi-connectivity networks and leveraging mobile edge computing capabilities. With the complexity of dense and ultra-dense networks, significant benefits arise from having increased programmability near the edge of the network.

Outlook for 5G ultra-dense networks

LTE and LTE-A will enable ultra-dense network deployment with minimum user cell edge data rates of 10-20 Mbps with monthly subscriber data of 20-50 GB data. In 2030 even higher data rates and data consumption is envisioned and LTE will no longer suffice.

It is clear that achieving the above requirements in all cases is not practical. Sub-millisecond latency and extreme data rates using new cmWave and mmWave spectrum calls for wide distribution of the processing, close to the antennas and the end-user. All areas of the networks will not use these extreme features. Further, the performance difference between small cell and macro layer starts to increase and achieving scalability at lowest possible network cost calls for a multi-layer approach. Finally, with UDN levels expected in 5G, control and support functions for better network optimization and automation will be needed.



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