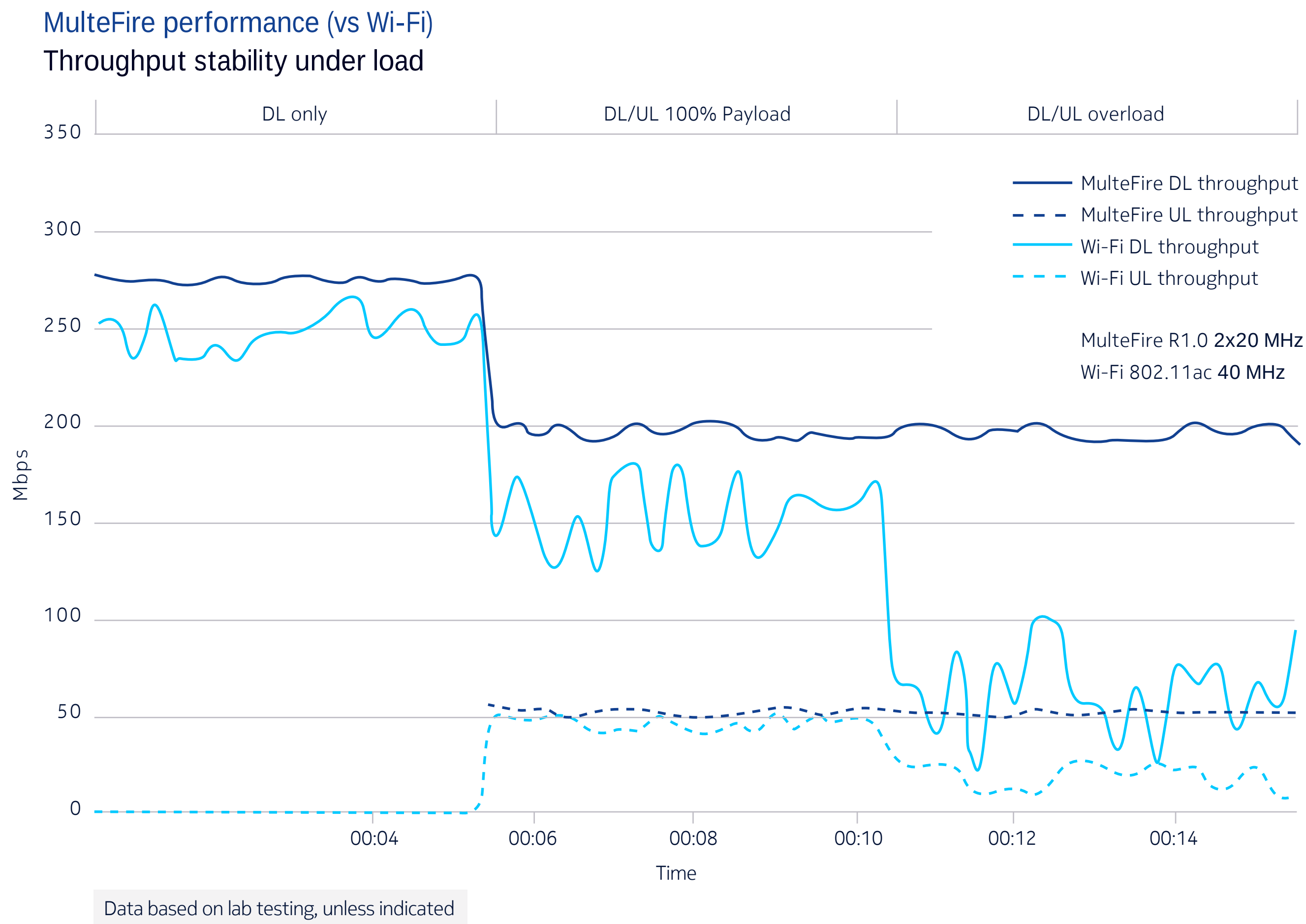
)LJXUH&RPSDULVRQRIWKURXJKSXWVWDELOLW\GHURQORDGRI/7((DQG)LUHDQG:L)L



7KH:L)LVWDQGDUGLQWURGXFHVWKHSRVVLELOLW\RIDGGLQJWKHLGOHURQWKHXSOLQN8/EXWQRWRQ
the downlink (DL). The number of bandwidth resource blocks per MHz is much lower and the resource
DOORFDWLRQGHVLJQHIRUWKHLUPRELOHVPVDUHWRDVDGYDQFHG7KLVPHDVVHVFUDOHEHEHVVORUHKH
HTDWHVWRRUHEDGLGWKWRWRGDPRWL:L)LVROWLRQGRWLPSOHPHQWWKLV8/VKHGOHUDQG
LWUHPDLVWRHVHHLIWKLVLOORU7KLPSOHPHQWDWLRQVKHGOHUZLOORQO\HDVLOIDWRWR
LPDFWRL:L)LDFFHVVRWVEHEDVHWLWLOOUHDVHPLFURRVVRIWKLWHUORHGHOLHGVWDJHV
(3(HTLUHPHQWVDQGGHROHLW9HQGRVPDLWLDOOEHUHOFWDWWRFRPSOHPHQWDVKHGOHU
because of the risk of becoming uncompetitive.

High multi-user capacity

7KH(GQHUDOSO\XUROHLQHQEOLQJKRRWLFXFDELWEVXSSRUWLQJVHUDQGGUHG
GHYLFHVSHUFHOO7KHUHLPSOHWKH1RNLDOHL[RQHVPDOOFHOOVIRQIRULWPDURFDELWFD
QGOHXWRDWLYHOFRPPXQLFDWLQJXVHUVPDOOFHOOZLWKRXQGFRUHFRQQHFWHGWRLW
:L)LLVHVIRUIRUHLDOORWLRVDQGLWVHUIRUPDFHUPEOHVKRPHWKHGHYLFHVDUH
DFWLYHLPSOLDWLRQ,WVHVRWVHWHGVWRLOLDOOEHOQGVWULPSOHPHQWDWLRQ
it will be critical to have the additional headroom that LTE can provide.

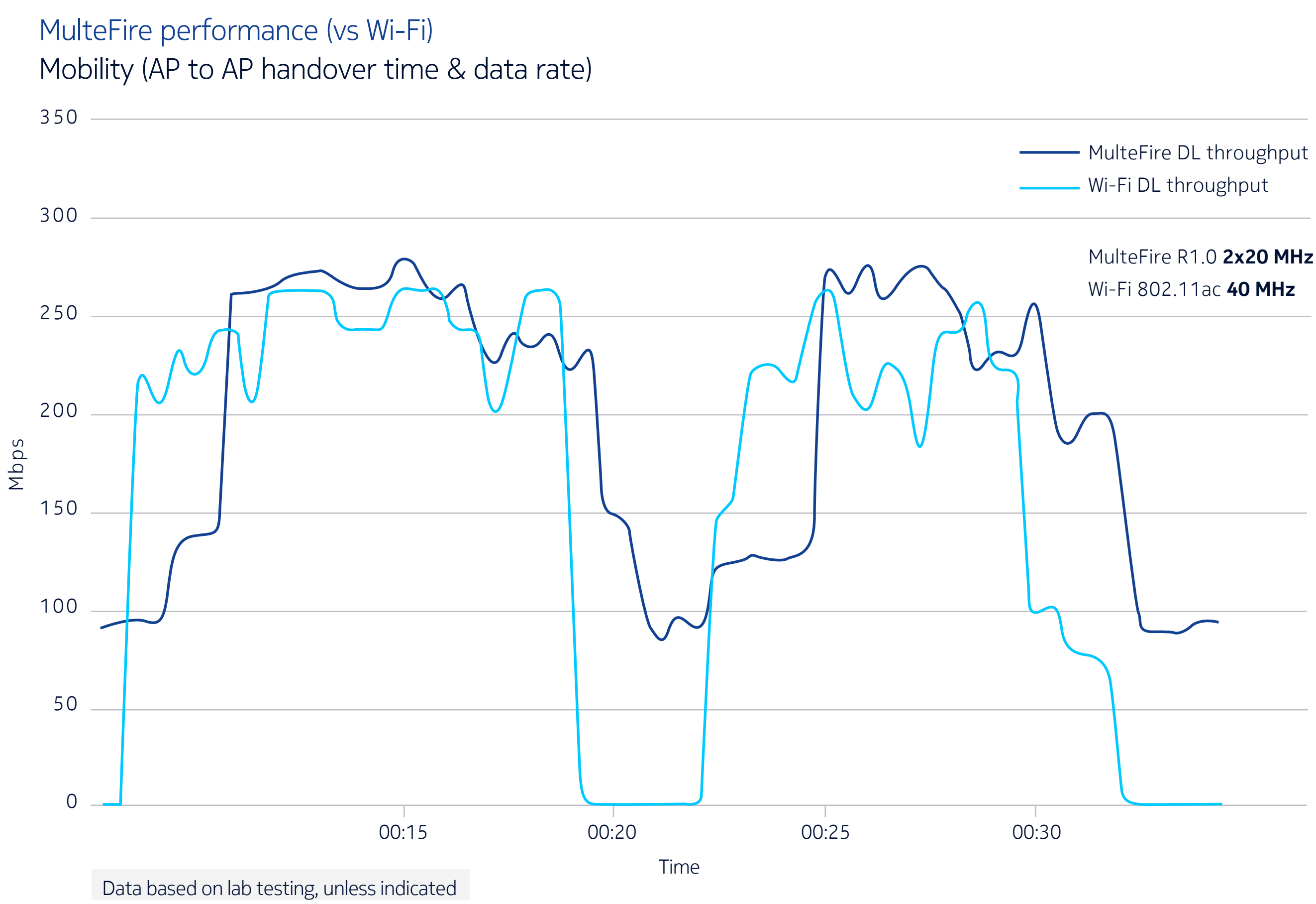
Full mobility

Wi-Fi is part of the IEEE 802 set of LAN protocols. Its initial design intent was to connect computers in homes and offices where only limited mobility was imagined. In contrast, LTE comes from 3GPP mobile radio standards with a key requirement for mobility. This requirement includes vehicular speed up to 350 km/h, which will enable the network to maintain live LTE connections for high-speed trains such as those found in France, China and Japan. The big difference is that mobility with Wi-Fi is mostly device driven and varies from one device to another. Mobility on 3GPP is a coordinated action between the device that detects and reports on its environment and the network core elements that analyze this data to look at all possible handover candidates and coordinate the handover with the target mobility BTS and the devices.

The mobility feature of 3GPP wireless technologies is particularly useful for industries that have large campuses with combined indoor and outdoor spaces. Many of these industries rely on different kinds of vehicles, including some that move at higher speeds, such as driverless buses, elevators and drones. The ability to maintain connectivity during handovers between radios is critical. This is a weakness in the Wi-Fi standard. Dropped connections can lead to software and data transmission problems that cause Wi-Fi-connected vehicles to crash.

In lab testing, we have observed disconnection–reconnection times of up to 15 seconds for Wi-Fi networks. In real life, we have seen factory AGVs suffer from repeated failures as they pass from one Wi-Fi access point to another. Changing the communication system to LTE or 5G quickly fixed these systematic failures.

Figure 5. Measuring mobility and handover times for LTE (MulteFire) versus Wi-Fi.



One wireless network for all applications

Higher education institutions can simplify their operations and significantly reduce cost by moving from multiple application-specific networks to a single network that handles all types of loads. A private 4.9G/LTE network offers better capabilities and performance than any other type of wireless network and will support a smooth evolution to future 5G network technologies. It can tackle all types of traffic while offering plenty of capacity and room to grow.

In addition to supporting high-data-rate, low-latency applications, LTE release 13 standards specify new IoT protocols (LTE-M and NB-IoT) that are particularly well suited for sensor-type devices. These protocols offer reduced complexity, optimized power consumption and lower data rates (LTE-M supports applications up to 1 Mbps and NB-IoT to 200 Kbps). Modems that use these protocols can run several years on battery power alone. These capabilities make it simple to deploy sensors in campuses or inside machines. LTE-M and NB-IoT operate with the same LTE network and equipment. Supporting them is a baseline capability of the Nokia industrial-grade private wireless solution.

When we deploy private LTE networks on campuses, we often find that enterprises or institutions have private mobile radio (PMR) or digital mobile radio (DMR) communication systems, such as TETRA or P25, that would need to interconnect and interoperate with LTE. Nowadays, these services can be implemented as group communication applications, such PTT and PTV, that run on top of LTE (and eventually 5G). They advantageously replace aging private radio systems and add new functionalities.

Total cost of ownership

The benefits of private wireless networks that can connect many things, machines and people are obvious. But how do these networks compare to CAT cabling or Wi-Fi alternatives with respect to TCO?

Given the multitude of IoT sensors and machine-based devices to connect in most Industry 4.0 implementations, traditional LANs will require a significant investment in cabling and switches. This will lead to more complex LAN architectures. Although each LTE BTS will require an Ethernet or microwave backhaul connection, it will be able to scale easily and connect thousands of workers, machines and sensors. This will greatly reduce the cost per endpoint.

Wi-Fi is often seen as a very cost-effective solution. Its combination of low cost and simplicity is its strength in IT-like applications. To compare the TCO of a private LTE system to that of a Wi-Fi system, we need to consider four key differences and factors at a network/system and performance level.

- An LTE BTS (or small cell) is more expensive than a Wi-Fi access point. The higher-powered radios and scheduler capabilities of LTE BTSs account for much of this cost difference. As described above, these capabilities are part of what makes LTE much better than Wi-Fi at addressing the critical application requirements of higher education institution campus users. The higher-powered radios in an LTE BTS are one of the reasons LTE provides much better coverage than Wi-Fi. For any given site area, an institution will require five to ten times fewer LTE BTSs than Wi-Fi access points. This will offset the increased cost per small cell by lowering installation and maintenance costs.
- LTE requires a core and Wi-Fi does not, except for management and user authentication. LTE also requires coordination between the BTS and other features that operate centrally. The core enables device mobility, coordination for multi-cell deployments, better interference management, QoS differentiation and improved security and availability. Thanks to function virtualization, LTE core solutions have been adapted to suit the smaller deployments required in higher education institution campuses. For example, one Nokia private LTE core solution can operate the seven or eight functions required for private LTE on a mini PC-sized server.

- LTE needs SIM cards or eSIM to authenticate users. It strictly controls who has access to the network and provides much greater security than Wi-Fi. Most Wi-Fi hacking techniques rely on breaking the authentication methods used in a given network.
- LTE networks are often seen as more complex to operate and manage. The Nokia private wireless solution makes the best use of self-organizing network (SON) features to ease deployment and optimization, while featuring an easy-to-use management portal. In other words, higher education institutions can avoid the complexity associated with LTE if they want to. Institutions can also take advantage of the full capabilities of our operations and management system if they want the ability to adjust parameters to maximize network capabilities and performance in the future.

With so many parameters to account for, including frequency, site size, indoor and/or outdoor deployment and number of users, it is difficult to provide a generic answer about how TCO compares between private LTE and Wi-Fi systems. Our experience shows that similar-sized private LTE and dedicated Wi-Fi campus networks that reliably support the same critical wireless applications and number of connections over the same coverage area have a comparable TCO.

The two big pluses for LTE are that it has a much larger coverage area, which lowers the initial CAPEX and installation cost, and that it has much higher capacity in terms of active devices, which reduces the need for future investment to scale the network. These two factors tend to compensate for the extra cost of the LTE radios and the need for a core network. LTE offers additional savings by reducing the complexity of the LAN infrastructure and providing more flexibility wherever it replaces CAT cabling. In addition, LTE can often replace aging PMR and DMR networks, and it can offload existing IT Wi-Fi networks so that they operate more efficiently.

Conclusion

New and evolving demands are enabling higher education institutions to digitalize the tools and services they provide on their campuses. To make a quick and successful digital transformation, these institutions will need wireless solutions that can overcome the capacity, coverage and feature limitations of their existing Wi-Fi networks. These networks are well suited for day-to-day business communications but are not optimized for business- or mission-critical communications.

Private 4.9G/LTE (and future 5G) networks offer a solution to this challenge. These networks enable higher education institutions to leverage 3GPP technologies and new spectrum options to provide the security, reliability, coverage, mobility, capacity and flexibility that digital and Industry 4.0 applications demand. By complementing Wi-Fi with private 4.9G/LTE networks, they can power a new generation of campus services that will address the changing needs of staff and students while reducing network TCO.

Abbreviations

3GPP	3rd Generation Partnership Project
AGV	automated guided vehicle
AR	augmented reality
BTS	base transceiver station
CBRS	Citizens Broadband Radio Service
DL	downlink

DMR	digital mobile radio
eSIM	embedded SIM
FCC	Federal Communications Commission
GBR	guaranteed bitrate
IoT	Internet of Things
LAN	local area network
LMR	land mobile radio
LTE	Long Term Evolution
LTE-M	LTE-Machine Type Communication
MIPS	microprocessor without interlocked pipelined stages
NB-IoT	Narrowband IoT
OFDM	orthogonal frequency-division multiplexing
OFDMA	orthogonal frequency-division multiple access
PMR	private mobile radio
PTT	push to talk
PTV	push to video
QCI	QoS class identifier
QoS	quality of service
RF	radio frequency
SC-FDMA	single-carrier frequency-division multiple access
SIM	subscriber identity module
TCO	total cost of ownership
UL	uplink
VR	virtual reality

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We create technology that helps the world act together.

As a trusted partner for critical networks, we are committed to innovation and technology leadership across mobile, fixed and cloud networks. We create value with intellectual property and long-term research, led by the award-winning Nokia Bell Labs.

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Nokia OYJ
Karakaari 7
02610 Espoo
Finland
Tel. +358 (0) 10 44 88 000

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