5G Micro-operators for the Future Campus: A Techno-economic Study

Jaspreet Singh Walia
Dept. of Communications and Networking
Aalto University
Espoo, Finland
jaspreet.walia@aalto.fi

Heikki Hämmäinen
Dept. of Communications and Networking
Aalto University
Espoo, Finland
heikki.hammainen@aalto.fi

Marja Matinmikko
Centre for Wireless Communications
University of Oulu
Oulu, Finland
marja.matinmikko@oulu.fi

Abstract— **In this paper, we propose a deployment framework for future indoor small cell networks that will be beneficial for the venue owner/campus, micro-operator (uO), end-users and Mobile Network Operators (MNOs). The research is motivated by ongoing struggle to improve indoor coverage, to meet ever increasing capacity demands and to develop 5G access solutions to be ready for future use cases. The framework conceives an indoor small cell deployment for the campus, operated and managed by the uO, which leverages network slicing to provide the campus with local customized service, while at the same time also acting as a neutral host for participating MNOs. The proposed framework will be beneficial in terms of reduced costs, additional revenues, dedicated services, coverage, and spectrum utilization. In the end, the framework is contended to be economically viable and more beneficial than Wi-Fi deployments. The total cost of ownership (TCO) is calculated per access point type and then the TCO for current total capacity is calculated for each option. The analysis shows that although small cells are expensive on a unit basis but the overall network can be cheaper and more beneficial than a Wi-Fi deployment.**

Keywords—5G, Micro-operator, small cell, Wi-Fi, Campus, Enterprise, Multi-operator, Multi-tenancy, Total Cost of Ownership

I. Introduction

The evolution of communication technologies from 1G to 3G and 4G has helped people connect all over the world and the transition to 5G is not so far in the future. 5G will provide improvements over 4G in terms of higher bandwidth, wider coverage and lower latencies. Apart from this evolution we will see a revolutionary change in the services and use cases. We will see the idea of Internet of Things (IoT) and Machine-to-Machine (M2M) communications come to realization. It is safe to say that 5G will not only bring connectivity to people but also to machines and things, thus bringing about a smarter world.

In 2016, 4G was already carrying 69% of global mobile traffic which will grow to 79% in 2021. By as early as 2021 5G is expected to be carrying 1.5% of global mobile traffic [1]. Factories, campuses, offices, hospitals, emergency services, transportation, industrial automation, etc. will reach tremendous levels of efficiency and productivity. These use cases will require very low end-to-end latencies and high reliabilities and this can be fulfilled by better access technologies and improved core networks. Higher frequencies like millimeter waves (mmWaves) can fulfill higher data rate requirements and they work well in short range and line of sight (LOS) scenarios. Many IoT devices will require profile generation and account operation. Operators managing the account operation must be able to customize services based on customer service requirements. Network slicing is expected to be the technology enabler in this respect. Coverage for future use cases requires almost 100% coverage including indoor locations and there is a need to achieve this without significant costs in planning, deployment, management and power usage. The development of these services will require context aware dedicated local networks and enhanced M2M and IoT capabilities with higher bandwidth, higher capacity, lower latency and higher reliability. A lot of this communication takes place indoors and future deployments of local wireless networks must help meet these requirements indoors. The demand for indoor capacity and coverage has been increasing dramatically, and as networks keep getting denser, installing more macro cells is not going to be economically viable and neither will it reach the required penetration indoors. Instead, macro cell capacity needs to be complemented with in-building small cells. Currently, indoor wireless communication is primarily handled over Wi-Fi, and as easy it is to deploy Wi-Fi access points, it is not as easy to maintain future capacity demands as Wi-Fi networks are getting saturated worldwide [2]. Wi-Fi offload for macro cells can be utilized for complementing macro cell capacity but this doesn't help achieve the quality of service (QoS) that small cells can help achieve. Thus, in the future there must exist a business actor that takes up the role of planning, installing and managing the in-building small cells.

A Micro-operator (uO) [3]-[5] is a business actor that will be able to provide local customized wireless connectivity. The uO concept allows different stakeholders to take a local operator role and exploit their domain specific knowledge in high-demand areas such as shopping malls, hospitals, campuses and enterprises. They could enter the mobile market to serve MNOs' customers in high-demand areas or complement MNO offerings

The work has been performed in Aalto University, under the uO5G project.

by tailored service delivery to uO's own customers. The emergence of uOs is dependent on regulations which were discussed in [5]. The uO can take different realizations depending on the use case. Initial revenue models in campus use cases were depicted in [3].

II. Methodology

To build the future uO deployments, it is imperative to study and develop network slicing, network sharing and small cells, and to analyze the techno-economic viability of the same. We will utilize the ongoing standardization on network slicing and network sharing scenarios to develop possible scenario that will be served by the uO. Then, we define a framework for indoor small cell deployment operated and managed by uOs that leverages network slicing to provide local customized services for the selected use cases, while at the same time acting as a neutral host for multiple MNOs. Later, the techno-economic viability of such deployment for campus network is analyzed. The campus use case was chosen for this study as it is a culmination of high density of end users, IoT and emergency services. The economic data for this analysis was collected from previous studies, expert interviews and independent market research.

III. Standardization and Enabling Technologies

A. Standardization

The 3rd Generation Partnership Project (3GPP) technical specifications define network slicing architecture [6] and describe various scenarios for network sharing [7]. A network slice is defined as a logical network that provides specific network capabilities and network characteristics. It defines three types of slices; i) eMBB (enhanced Mobile Broadband) ii) URLLC (ultra-reliable low latency communications) and iii) MIoT (massive IoT). It also defines a network slice instance as set of network function instances and the required resources which form a deployed network slice. Complementing the ongoing standardization and industry activities, network slicing is briefly defined in the next subsection. In network sharing specifications, Master Operator (MOP) is defined as the one that is responsible for the deployment, operations and management. It also defines Participating Operators (POPs) as those that only participate in the sharing of network facilities provided by the MOP. It defines three scenarios; first where one of the POPs is also the MOP, second a joint venture between POPs to form a MOP, and third a third-party acting as the MOP. In this context the uO (a third-party or the facility owner) is the MOP and all MNOs are POPs.

B. Network Slicing

In general, network slicing can be defined as a means to isolate network capacity into customized network slices to meet specific service requirements. A network slice is a logically isolated network operating over the physical network. When comparing to existing network sharing paradigms it can be defined analogously to content based, network component based and requirement based sharing. Network slicing can exist in the Radio Access Network (RAN) or Core Network (CN) or both. Thus, all or a part of the network can be sliced, from servers to user devices. The physical content or server resources are sliced into different slices for different use cases. For different content slices there can be different applications running on the servers. These content slices can be assigned to MNOs, Mobile Virtual Network Operators (MVNOs), service providers (SPs) or uOs depending on their customers. One service can use one or several slices. The operators can create virtualized network components, for example, MNO can provide a RAN slice to MVNO, or both RAN slice and CN slice to a SP, or e2e network slice to serve end-user, or a uO could provide local network slices to MNOs, MVNOs, SPs and end-users. The network slices to be used will depend on the e2e requirements such as, bandwidth, data rate, number of users, latency, etc. The designing of network slices for each use case will require setting up a Service Level Agreement (SLA).

There are other existing virtualization techniques like Virtual Private Networks (VPNs) and Differentiated Service (DiffServ) that provide differentiation in the traffic and can prioritize and logically separate different types of traffic but not the same type of traffic for different tenants and offer true multi-tenancy, something that is expected to be achieved in 5G. Network slices will provide customers with dedicated, flexible and customizable virtualized network resources. The network slices will be use case specific and their creation, management and termination can be handled by either MNOs, MVNOs, uOs or service providers. Network slicing opens up a whole new way of provisioning services and doing business. Network slices can be a part of the product/service offering of a uO. The lifecycle of a network slice as a service offering in a business model would include, customer specification (request timing, duration of request, QoS, required resources, network functions, etc.), slice design according to those specifications, extensive marketing and pricing, deployment, operation and management and finally termination.

C. Small Cells

Small cells are low cost and low power base stations that have shorter coverage area relative to macro base stations. Small cells can be deployed both indoors and outdoors. Small cells are used for offloading macro traffic or to complement macro cell capacity in very dense areas. Small cells are being deployed in coordination with macrocells forming heterogeneous networks. A drawback of heterogeneous networks is expensive backhaul. Small cells are classified as femtocells, picocells and microcells. Generally, femtocells support a range of 10-50 m, picocells support a range of 200 m, and microcells support a range of 2 km. Femtocells are deployed indoors and can be user-deployed or operator deployed. Picocells and microcells can be deployed indoors and outdoors and are mostly operator-deployed to usually improve outdoor to indoor coverage. The most important to the micro-operator concept are femtocells and picocells as these lead to significant increase in indoor capacity and coverage and are simple plug-and-play devices. Another advantage is that they utilize user's existing network as backhaul and being indoor deployments, they can better guarantee sufficient indoor coverage and low latencies.

TABLE I. WI-FI VS SMALL CELLS DEPLOYMENT

Key Differences	Wi-Fi	4G	5G
Spectrum	Unlicensed	Licensed and Licensed Assisted Access (LAA) to use unlicensed spectrum. LTE-U, MulteFire (not standardized yet)	Licensed and Unlicensed
Frequencies	2.4, 5 GHz	Multiple frequency bands worldwide. Unlicensed on 5GHz.	Multiple frequency bands worldwide including frequencies above 6GHz (mmWaves).
Bandwidths	5, 10, 15, 20, 40, 80 MHz	5, 10, 20 MHz Maximum carrier aggregation 100 MHz	Expected to have wider bandwidths than 4G
Spectral efficiency	3.61, 3.75, 5.42 bps/Hz	3.75 (SISO), 30 (MIMO) bps/Hz	Expected to have higher spectral efficiency than 4G
Max. capacity per access point	72.2, 150, 433, 866 Mbps	LTE 300 Mbps, LTE-A 1 Gbps (theoretical 3 Gbps)	Expected to be 20 Gbps
Status	Widely deployed indoors	Widely deployed outdoors but being deployed indoors	Expected to be completely standardized in 2020
Deployment Scenarios	Indoors	Indoors and outdoors	Indoors and outdoors
Performance	Low QoS, Best effort	High QoS	Higher QoS than all existing technologies
Assumed capacity per access point/base station for the campus	400 Mbps	500 Mbps	5 Gbps

Previous studies show better performance indoors with use of femtocells [8] and comparison of picocells and Wi-Fi densification [9] shows that in the long run small cells will be cheaper and more beneficial. Regardless of whether it is a small cell or macrocell the average throughput in all cases is the same, given the channel bandwidth and number of sectors is the same. As the size of the cell reduces, the capacity in the area increases because capacity is inversely related to radius of the cell. So, in an ideal situation if 4 small cells with half the radius of a macrocell are deployed, then the capacity is quadrupled. Although the capacity increase will depend on a lot of factors such as wall penetration losses, user mobility and distribution, fading etc. but it is safe to assume that capacity increase will be on the order of the number of small cells deployed. Also, the users in campuses and enterprises are located closer to access points and with lower mobility there should not be a problem in keeping this capacity assumption. Femtocells are the best candidate for in-building high capacity deployments with low mobility of users, as the cell radii are smallest and capacity increase can be the highest. Whereas, if it were a combination of fast moving users and vehicles in the outdoor campus area a combination of picocells with femtocells can be used. Placing multiple picocells with higher power, close to each other will cause higher interference than femtocells which can be placed closer with lesser interference.

Currently, a lot of campus and enterprise networks have Wi-Fi already deployed but it doesn't offer the QoS offered by 3GPP cellular solutions. Wi-Fi deployments will continue to exist and can be a great way to reduce costs further with interworking between femtocells and Wi-Fi. There are differences in IEEE and 3GPP standards. A comparison between small cells and Wi-Fi deployments is shown in TABLE I. The term 4G is often used in place of LTE and vice versa. There are many versions of LTE, different in terms of releases. Over the years the movement has been towards unlicensed spectrum by incorporating Licensed Assisted Access (LAA), enhanced LAA (eLAA) and other different techniques to utilize unlicensed spectrum. Apart from LAA there are other technologies based on LTE that utilize unlicensed spectrum such as MulteFire. The standardization of these is not there yet but it is expected that they would be employed in the future since they utilize unlicensed spectrum and can provide significant improvements in coverage and capacity without higher costs. If future requirements of100 Mbps data rate available per user and this will be possible by going towards higher frequencies and using wider bandwidths. Ongoing studies on 5G waveforms have shown that spectral efficiencies of 7.2 bps/Hz, that is, double that of 4G are possible for 5G [10]. Next step should be to increase the bandwidth and with having 5 times increase in the bandwidth from 20 MHz to 100 Mhz, a total 10 times increase can be expected in the data rate.

IV. MICRO-OPERATORS FOR THE FUTURE CAMPUS

A. Campus Network

The current local area network (LAN) for the campus on the high level consists of the components shown in figure 1. There exist server rooms in different departments of the campus utilized for data storage and local processing needs. There can be distributed or centralized LAN controllers for controlling the traffic depending on the requirements of the campus. The access technologies employed are Wi-Fi and Ethernet. There exist outdoor small cells (picocells and microcells) to improve the coverage of the wide area network (WAN) but there aren't any indoor small cells as part of the LAN. There is still lack of sufficient indoor coverage and there exists a gap between LAN and WAN which could be troublesome in the age of Internet of Things (IoT) with campuses and businesses spread over vast geographical areas in the future.

In the Aalto University campus area that was studied there were 3 macro base stations offering wide area coverage to mobile users and approximately total 900-1000 indoor Wi-Fi access points in all the buildings of the campus. The number of Wi-Fi access points in each building depends on building size, location and types of services. Typical enterprise Wi-Fi access points calibrate the transmitted power according to surrounding access points and planning is done to provide LOS connectivity in almost all office rooms, lecture rooms, auditoriums, hallways and open indoor spaces, while maintaining the aesthetics of the building. A major issue that is overlooked is the wired infrastructure as it is quite expensive to use fiber connections for backhaul. Many times, such installations are skipped by small venue owners and simply leased from operators or internet service providers. These costs then appear in the operational expenses rather than capital expenses. For long term planning and depending on the expected rise in data traffic, the venue owners can sometimes invest heavier on the wired infrastructure to support the future wireless deployments. Also, it is not reasonable to deploy and coordinate very old and new access points that have significant updates in hardware and firmware, thus, the typical lifetime of access points is kept around 5 years. There is logical separation in the Wi-Fi access provided to students, teaching and other staff and guests. For example, the students and teaching staff have different affiliation and different access rights to the services. There are different networks, like aalto open (no authentication required), aalto (aalto credentials required) and eduroam (pan European wireless network for participating universities and authentication by own university's credentials). These different networks are logically separated and exist on the same Wi-Fi infrastructure. In addition, the campus has base stations dedicated to 5G research and constitute a test network for developing next generation core networks. This 5G architecture is described further in the next section.

B. *High Level Architecture*

The uO concept has been emerging as industry verticals are moving towards localized and dedicated services. The uO will be responsible for building indoor small cells infrastructure. It will be able to offer site-specific localized services, customizability, lower latency and higher reliability, which the MNOs find difficult to offer. In the proposed high-level architecture, figure 2, the access technologies are 3GPP femtocells in addition to existing Wi-Fi and Ethernet. The 3GPP femtocells will be a part of the LAN and thus could fill the gap between the WAN and LAN to make handovers for mobile users easier. The femtocells being plug-and-play devices and since they can utilize existing internet access links as backhaul, are the best choice for indoor wireless deployments but when it comes to larger open spaces, picocells can be considered. The uOs can operate on different types of spectrum including licensed and unlicensed bands. It is evident by the movement towards unlicensed spectrum such as LTE-Unlicensed, LAA, MulteFire (not a standard yet). Micro-licensing schemes were proposed in [5] to allow local spectrum licensing to promote new market entry. Software Defined Networking (SDN) separates the user plane and the control plane which allows the user plane and control plane to be scaled independently. This also means that they can be located at different locations. The control plane can be at a central site to make management (authentication, subscriber data, session handling, and policy control) simple and the user plane can be located at many different local user sites to bring it closer to the user as this will effectively reduce latency [11]. Network Functions Virtualization (NFV) technologies will allow to manage many heterogeneous IoT devices with scalability and flexibility in operating and managing network devices. Besides the core network, NFV can be applied to the RAN as well by centralizing the base band processing within the RAN equipment. Network slices can have different architectures based on the required services and the business models followed, but can share functional components. Network slices should be assigned a set of network resources in the physical infrastructure. This will improve flexibility, reconfiguration and expansion for new use cases. By the concept of network slicing, SDN and NFV it will be possible for coexistence of multiple operators and management functionalities provided by third parties. This approach makes the most cost-effective deployment possible as it will provide efficient management for resources and allow co-existence of different services with different QoS requirements. The Wi-Fi network access as previously provided with logical separation between networks among different type of users can in future be provided by assignment of network slices to different service types [6]. There can be different slices for students, staff and guests. Apart from this there will be network slices for participating MNOs which will help the MNOs to enter local networks and provide their services over their assigned network slice.

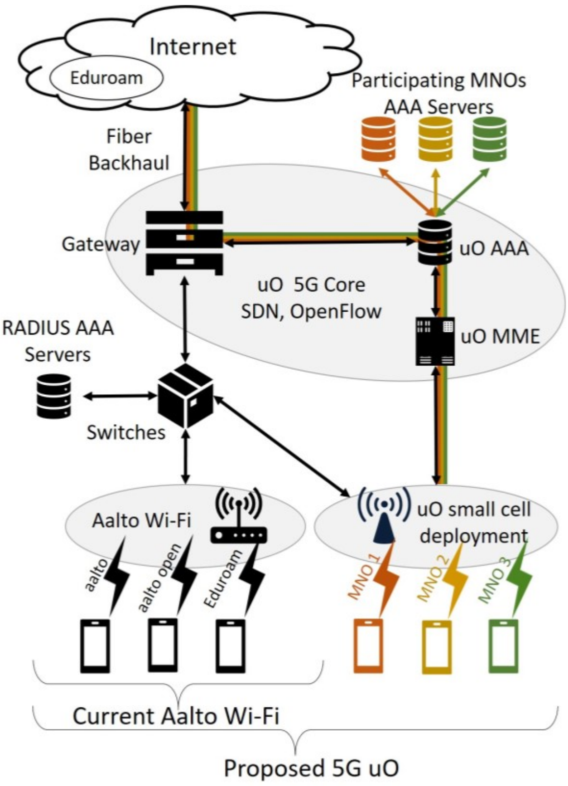

Fig. 1. Current Wi-Fi vs Proposed 5G uO small cell deployment for campus

In this ecosystem the indoor small cells will be deployed, operated and managed by the uO while the outdoor small cells and macro cells will be managed by the MNOs. But this will not solve the problem for existing MNOs until they are able to utilize the indoor small cell deployment. Thus, by offering network slices to the participating MNOs, the benefits can be reaped by all stakeholders in the ecosystem. The uO will be responsible for virtualizing its small cell network into slices. One, the micro-operator will operate the campus network with the dedicated slice for local well-tailored services. Two, the uO will provide MNO slices to all the MNOs who want to extend their wide area coverage indoors. This will not only benefit the end users and MNOs by improved indoor coverage but it also opens up another revenue stream for uO, as it can then charge the MNOs for accessing its local network. Thus, apart from acting as the local operator the uO also acts as a neutral host for the other MNOs. Here the uO is also the MOP and all other MNOs are POPs. The uO must have a local Mobility Management Entity (MME) or dedicated functions for the users inside the campus and also handle accounting operations for the MNO's subscribers locally and give access to MNO's to perform their authentication procedures when their customers are inside the campus network. This can enable seamless handovers between the wide and local area networks. The mobility management in cellular networks is a big advantage over Wi-Fi networks where mobility is very limited and handovers are not very smooth.

C. *Small Cells for Micro-operators-Deployment Framework*

Learning from the success of Wi-Fi and also the drawbacks of Wi-Fi, an indoor deployment framework for the high-level architecture described above, should be cost effective and consider the following factors:

- It should try, where possible to utilize existing infrastructure
- It should utilize licensed spectrum for highly reliable, low latency access and unlicensed spectrum to reduce costs
- It should bring enough incentives to participating operators to offload their macro traffic and provide better service indoors

The deployment framework considers the above factors and describes the various steps involved in the deployment of a cost effective uO deployment beneficial for all stakeholders:

Prior considerations:

The planning, deployment and management of the network should consider certain prior consideration:

- User Requirements: The user requirements such as capacity, QoS, user distribution, mobility, type of applications etc. is one of the starting points for planning the network deployment. In the selected campus case, there are many different type of users; students, teachers, staff and visitors. They have different capacity requirements, different authentication and affiliation based access rights which is currently handled by having open and closed Wi-Fi access. This user specific access and dedicated services can be provided by network slicing and allocating required resources to user groups. The user distribution varies with the type of rooms; office room, lecture hall, auditorium, open indoor spaces, hallways, libraries, restaurants and parking garages.
- Size, shape and type of building: The size, shape and type of building play an important role in deciding how the user requirements can be satisfied. The deployment has to take into account the wall penetration losses and the requirement of LOS connections. The path losses and calibration of transmission power and interference with other small cells and with macro cells must be considered. This will help in deciding the possible coverage and available capacity per small cell. The building that was studied in the campus has 3 floors and a total floor space of 10000 m2 with varying distribution of users in the type of rooms as discussed before. Higher densities call for higher capacity whereas open indoor spaces call for larger coverage.
- Existing network infrastructure: It is important to consider the existing infrastructure to reduce capital expenditure. The building that was studied has both closed and open Wi-Fi deployments. The building has 100 access points. The number depends on the path losses and interference with other access points and this gives a good estimate of number of access points for the selected campus type of building and floor space of 10000 m2. In this case the coverage per access point comes out to be 100 m2. Each access point can ideally support a maximum of 50 users giving a maximum peak total number of users in the building to be 5000. There are existing LAN controllers, servers, switches inside the building LAN and also fiber and copper connections existing inside and between buildings. This existing network can and should be used when planning the small cell deployment.

Planning:

- Coverage or capacity oriented: The number of access points can be different for a coverage oriented approach and a capacity oriented approach. In a coverage oriented approach, the focus is on providing access in all areas according to the user distribution. The number of access points in this case is simply the total floor area divided by the coverage per access point. In this case, lower number of high powered small cells can provide good coverage. In a capacity oriented approach, the focus is on providing higher capacity for higher density of users with higher data rate requirements. In this case it is a good idea to have higher number of low powered small cells. The requirement in a campus is to have full indoor coverage and high capacity and thus there should be a balance between the approaches.
- Equipment type – Femtocell or picocell: Considering both the above approaches, it is possible to deploy high powered picocells in large open spaces but this will increase the interference problems with other picocells and femtocells and also interference with macrocell in case of picocells on the periphery of the buildings. It is a good idea to consider a higher number of low powered femtocells that will offer lower interference and higher capacities.
- Placement of equipment: The placement of femtocells can follow the existing deployment and simply replace existing Wi-Fi access points or better planning can be done by the uO depending on the locations of macro base stations and path loss and interference measurements. Placement of femtocells in existing Wi-Fi locations can reduce planning costs but there can be coverage or

interference issues, for example, if transmission power is higher or lower. The transmission power should be well calibrated to find a balance between coverage and interference.

Deployment:

- Installing the access points: The femtocells are easy to install being plug-and-play devices. The uO must be responsible for installing the access points in the right locations. The power, backhaul, and other infrastructure is assumed to be already built out.
- Network slices – dedicated use case specific slice and participating MNO slices: The uO will be responsible for virtualizing the network functions and for creating the network slices according to the user requirements. The uO will be serving the use case specific network slices to the campus users and also act as a neutral host to the participating MNOs. The motivation for this approach is to give the MNOs some incentive to improve their indoor coverage without much expenses. For the uO this opens up a new revenue stream apart from the existing revenue generated from serving the campus.
- Network slice business model: The uO's role will involve the creation, provisioning, management and termination of network slices. The uO must select the business model for network slicing according to the requirements, available expertise and marketing.

Operation, Administration and Management:

- Network Slice OAM and equipment OAM: The uO takes up all the OAM roles and other participating MNOs only participate in the sharing of the network and managing their own accounting and authentication operations.
- Monitoring of QoS and optimizing the network: The uO also monitors the QoS to provide the service according to the SLAs with the campus and the MNOs. The uO should maintain, optimize and improve the network to deliver on the agreements.

Following the framework, a cost effective uO deployment can be achieved which will be beneficial to all stakeholders. The economic viability of this framework is analyzed in the next chapter.

V. TECHNO-ECONOMIC ANALYSIS

As the amount of traffic generated indoors keeps on increasing, the MNOs find it hard to extend their capacity and coverage indoors. Deploying more macro cells or outdoor small cells doesn't help much as they become inefficient when it comes to building penetration losses. Each MNO might wish to deploy their own infrastructure indoors but it might not be economically viable for each one. The major concern in such expansion should be the capital and operational costs. These costs can be reduced if shared among the MNOs. The uO as a third-party can act as a neutral host and be the master operator in network sharing scenario. In [12] two deployment scenarios are considered for a single MNO, one with only macro cells and second with macro and femtocells; the latter having lower deployment costs and higher energy savings. The costs of deployment and energy saving would be even lower in the proposed uO framework due to sharing among different operators. Shared small cell deployment infrastructure for uO will help reduce costs and help deliver high QoS indoors and with availability of better services indoors there will be more revenue generated by users.

It would be unreasonable for one operator to setup their small cells indoors as they would only serve their own customers. Having multiple MNOs setup their small cells indoors would also not be preferred due to interference and basic aesthetic reasons as the building owners might not prefer to overcrowd the building architecture with cabling and base stations. It is preferable that transition or integration of 3GPP small cells in the local networks happens on the existing Wi-Fi access point locations. MNOs could employ network slicing to share RAN with other participating operators in Multi-Operator Core Network type scenario [7]. The MNOs could then sell network slices as a service to other participating operators. The MNOs however need to find high value to provide localized indoor services, which is not the case today [13]. Macro cells have larger size and higher costs related to site lease, installation, and power usage. Macro cells also have poor indoor coverage. Assuming that same capacity is provided by one small cell with same number of sectors as a macro cell, then the amount of capacity indoors will increase manifold by deploying a number of these in the right places.

As discussed in the previous sections the Wi-Fi access points can be replaced by femtocell deployments that will use existing network cabling, local servers, switches and existing internet backbone and or also utilize the internet backbone provided by participating MNOs. This will reduce the capital expenses of installation of the wired infrastructure and deployment costs for MNOs. Thus, in our comparative cost analysis for femtocells and Wi-Fi access points we have not included expenses for installation of the wired infrastructure and other network elements, as it is assumed to be already built out and it will be approximately the same for femtocells and Wi-Fi. Also, the costs for virtualization are a part of the operational expenses on the salaries of the personnel and roughly the same for each type of access point. The costs for femtocells are substituted with available LTE femtocells. It is expected that indoor small cell deployments will utilize unlicensed spectrum at frequency band 5 GHz and this has been incorporated in the calculations by not including costs of spectrum licensing. Apart from standardized LAA there are other unstandardized technologies such as MulteFire which can offer better performance than Wi-Fi but with the ease of Wi-Fi. This has been included in the comparison on a qualitative level. It is expected that such low-cost technologies will become more ubiquitous in the indoor deployments. The capital (CAPEX) and operational expenses (OPEX) for indoor LTE femtocells and Wi-Fi access points are compared in TABLE II and figure 2. The CAPEX includes the site acquisition, equipment costs, planning and commissioning and deployment costs. The OPEX includes annual site lease, power usage, operation and maintenance costs. These costs were estimated per access point. The actual costs can vary based on many factors such as location, brands, contracts and available expertise. These costs will offer a good estimation without over valuing any one option. The lifetime of an access point is assumed to be 5 years and the total cost of ownership (TCO) is calculated accordingly. New hardware is usually more expensive and so CAPEX for a 5G femtocell is expected to be higher whereas it can be expected that the OPEX will be on the same order of a 4G femtocell with virtualization incorporated. Further, the increased CAPEX in the future will be a small portion of the TCO over 5 years and thus the TCO of a 5G femtocell can be expected to be on the order of a 4G femtocell.

TABLE II. COSTS, CAPACITY AND BENEFITS COMPARISONS PER ACCESS POINT TECHNOLOGY

Costs (EUR)	Aalto Wi-Fi	4G Femtocell	5G Femtocell
CAPEX	1000	1200	Higher than 4G
Annual OPEX	600	750	On the order of 4G
TCO 5years	4000	4950	On the order of 4G
Assumed capacity (Mbps)	400	500	5000
Benefits			
Reliability	Low	Medium	High
Flexibility	High	High	Higher with network slicing
Scalability	Low	Medium	High
Security	RADIUS Server based authentication	SIM card (Hardware) based	SIM card (Hardware) based
Indoor navigation	Closest Access point based	Integrated GPS based	Integrated GPS based
Mobility Management	Very limited	Dedicated mobility management entity	Dedicated mobility management functions
Expansion to new Spectrum	Low	Medium	High
Network slicing	No	No	Yes

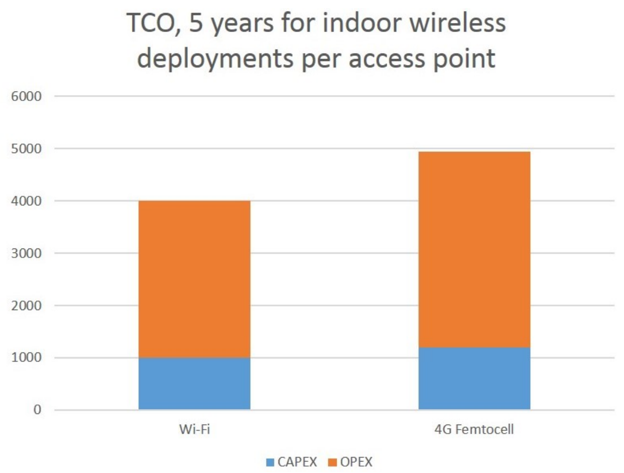

Fig. 2. TCO, 5 years for indoor wireless deployments per access point.

The differences in CAPEX and OPEX arise from higher complexity in technology, higher equipment costs and higher power usage. It is easy to deploy Wi-Fi access points but it is not as easy to meet future requirements. The reason behind Wi-Fi having lower operational costs is because it has less stringent performance, latency and reliability requirements. Wi-Fi access point CAPEX and OPEX are only about 80-85% of a 4G femtocell, but the capacity per Wi-Fi access point is lower than a femtocell. The number of Wi-Fi access points required to match the capacity and reliable performance of femtocells will be much higher. The benefits listed later in this section outweigh the higher costs per femtocell.

The assumed capacity per Wi-Fi access point is 400 Mbps on the more modern Wi-Fi access points while there are also some older ones 200 Mbps, as in the existing networks. The capacity per LTE femtocell can be limited by the existing wired backhaul but it is also possible to have wireless LOS mmWaves backhaul in the future or fiber backhaul that already exists to support higher capacity. We have assumed a peak capacity of 500 Mbps for 4G femtocells, although capacities higher than 1000 Mbps are possible even for LTE-A [14]. With fractional frequency reuse the target spectral efficiencies of 30 bps/Hz can be achieved [15]. Also, the capacities offered by 5G small cells are expected to be much higher but have not been used in the calculations to avoid over estimating the benefits in the TCO comparison. With these assumptions, a combined capacity of 40000 Mbps as being provided by 100 Wi-Fi access points can be provided by 80 Femtocells. It should be considered that proper coverage analysis should been done in the planning phase of deployment. The TCO for 80 femtocells (396000 EUR) is lower than 100 Wi-Fi access points (400000 EUR). There will be a larger difference if the peak achievable capacities of 1Gbps for LTE-A were used for comparison. The TCO for the two deployment solutions for providing same amount of capacity in the studied campus case are compared as shown in the figure 3.

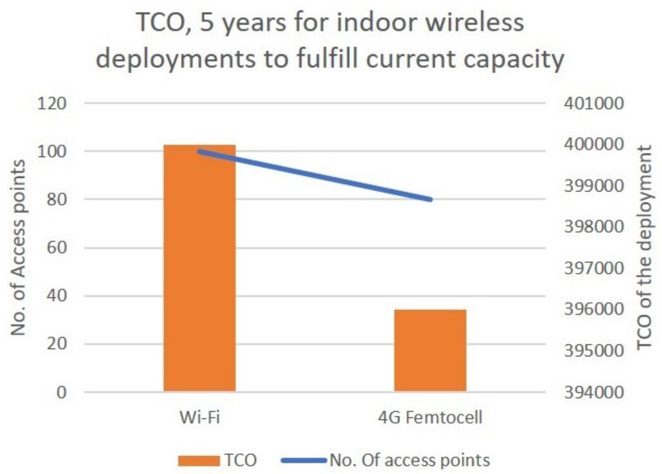

Fig. 3. TCO, 5 years, to fulfill current total capacity.

The estimates for current capacity requirements shows that 80 femtocells can satisfy the same capacity as 100 Wi-Fi access points. The total offered capacity of 40000 Mbps means that theoretically the data rate one user gets in peak situation (5000 users) is 8 Mbps. Alternatively, if the number of femtocells have to be kept equal to Wi-Fi access points then there can be significant total capacity increase from 40000 Mbps to 50000 Mbps. With 100 4G femtocells each user in the peak scenarios will be able to get 10 Mbps data rate. In [9] it was shown that densification of Wi-Fi networks beyond a certain level marginally increases the network capacity. The future demands are going to increase, and the current Wi-Fi technologies can certainly not satisfy future capacity demands without having unrealistically high number of access points. This points to the requirement of further enhancements in current 4G and future 5G femtocells to support higher number of users, better coverage and higher capacity.

This deployment framework of a uO in a campus incorporating network slicing, network sharing and small cells will have advantages for end users, venue owners, uO and MNOs in the following aspects:

- **Performance and Coverage:** Ability to provide better capacities in places with lower Macro cell coverage. A local network also provides better customer satisfaction in terms of providing solutions.
- **Dedicated services:** Ability to serve different groups of users; employees, students, staff, visitors with dedicated and secure services. Ability to monitor traffic and service utilization to continuously optimize the network.
- **Cost savings:** The costs of a small cell are considerably lower than on macro cell with clear cut savings in CAPEX (radio infrastructure, site acquisition, etc.) and OPEX (site lease, maintenance, power usage, transmission expenses, etc.) [12].
- **Additional revenues:** With better coverage and dedicated local network it will lead to higher network utilization and more revenue. Also, the uO will be able to charge MNOs for sharing the indoor small cell deployment by selling network slices.
- **Spectrum utilization:** A uO will utilize the micro-licensed spectrum or the unlicensed spectrum. The MNOs and service providers will pay the micro-operator to connect to the local network without owning the spectrum. This can serve a multi-operator system without very high spectrum licensing costs. Spectrum sharing with MNOs spectrum is also a possibility.
- **Power usage:** Campuses have high user traffic only during the day. It will be unreasonable for MNOs to use traditional methods to improve indoor coverage for some hours a day. Micro-operator deployment will be significantly cheaper in terms of power usage. Micro-operators could use low energy modes or even shut down some small cells based on traffic demands [12].

VI. CONCLUSIONS AND FUTURE RESEARCH

The deployment framework for uO proposed in this paper shows the benefits for all stakeholders involved; the end users, venue owners, uO and the MNOs. The uO deployment framework has been discussed from a techno-economic view and has been found to be viable for the campus case. The paper also compared different deployment options for in-building wireless access. Previous studies and building upon the expert interviews, it has been realized that building a shared indoor small cell infrastructure can help in improving indoor capacity and coverage. Femtocells are low-cost, low-power and plug-and-play devices can be deployed with the ease of Wi-Fi. The costs of femtocells and Wi-Fi access points are almost comparable with the latter being cheaper. There are advantages in latency, reliability and performance characteristics of the femtocells. Beyond a certain level Wi-Fi densification does not yield significant increase in network capacity thus making cellular options more scalable. It is also found that for the same amount of capacity, the number of femtocells required are lesser than Wi-Fi access points and this leads to lower overall TCO of a campus network. Thus, even when small cells are more expensive than Wi-Fi on a unit basis, the overall small cell network deployment can be cheaper and more beneficial than a Wi-Fi only deployment. For future research, the proposed framework can be applied to other venue types and detailed techno-economic analysis can be performed.

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