Bringing 5G Into User's Smart Home

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***Abstract*— A successful 5G Smart Home must be able to support 5G devices along with WLAN devices. This is not possible with the 5G specifications, and to remedy the situation, this paper proposes a 5G Smart Home Solution that combines the 5G network slice concept with a femtocell home router, supporting both 5G and WLAN access technologies. While making use of standard technologies, the solution has proven to be efficient and reliable. For that purpose, in this paper we propose a femtocell network slice architecture for 5G, utilizing WLAN in order to connect the user's smart home with the distributed cloud services.**

Keywords—Smart Home, Home automation, 5G mobile networks, 5G mobile systems, 5G network slicing, Femtocell, Internet of Things

I. INTRODUCTION

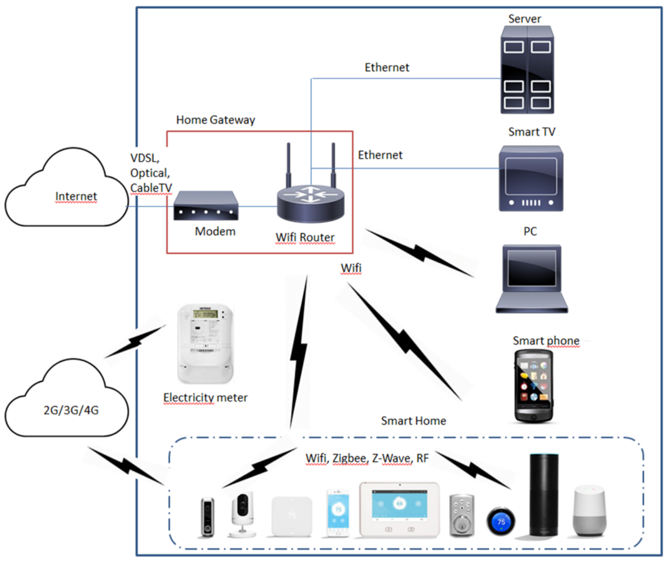
The ultimate promise of the 5th Generation Mobile Network aka 5G is to support a wide range of Internet of Things (IoT) applications such as Wearables, Smart City, Smart Home, Industrial IoT, Smart Grid, Connected Grid, etc. This constitutes an extreme challenge because these applications have quite different requirements in terms of bit rate, reliability, latency, processing and storage ability, security and privacy. To keep its promise, 5G will make use of the concept of **Network Slicing** to establish multiple logical networks aka network slice fulfilling heterogeneous requirements to accommodate each of these IoT applications.

Unfortunately, although most IoT applications are operating with devices having uniform requirements such as Wearables, Smart grid, Connected car, Smart farming, etc. there are others like Smart city, Smart home, Industrial Internet, etc. which make use of a variety of devices with diversified requirements. Furthermore, some current IoT applications like Smart home [1] consists basically of several applications such as Smart locks, Smart TVs, Smart security, Smart electricity meter, etc. which are using different wireless technologies such as ZigBee [2][3], Z-wave [4], Bluetooth [5], Wireless LAN [5], cellular, etc. and managed by different actors such as the home owner, security service, electricity company, etc. Consequently, when introducing 5G to user's home it is not realistic to expect all existing IoT applications to adopt 5G wireless technology and a better solution is required.

This paper presents the 5G4IoT Smart home solution experimented at the Oslo Metropolitan University Secure 5G4IoT Lab[1] within the scope of the H2020 CONCORDIA project[2], which is aiming at shedding light on how 5G network slicing can efficiently support Smart Home in terms of performance, management, security and cost. By combining the concept of network slicing and the femtocell notion with the Wireless LAN technology also called Home NodeB/Home eNodeB in 3GPP standards [6], our solution proposes for Smart home dual network slices sharing the same home router.

The paper starts with a short but comprehensive state of the art of Smart Home implementation that is studied scrupulously and the findings are summarized. Additionally, the 5G network slice concept is then explained. The core of the paper is naturally, the presentation of the Smart Home Network Slicing. Last but not least is a concise description of the pilot at the Secure 5G4IoT lab. The paper concludes with a few suggestions of further work.

II. STATE OF THE ART OF SMART HOME IMPLEMENTATION



[1] http://5g4iot.vlab.cs.hioa.no/

[2] https://www.concordia-h2020.eu/

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Figure 1. A typical current Smart Home

As depicted in Figure 1, most of European homes are todays connected to the Internet using one of the technologies like ADSL (Asymmetric digital subscriber line) [7], VSDL (Very high speed digital subscriber line) [8][9] optical fibre or CATV (Cable Television) [10] via modem (modulator demodulator). To establish a home network, it is necessary to connect a router to the modem. This router can quite often provide both Ethernet and Wireless LAN (WLAN) connections to various devices from personal computers, servers, TV, media systems and also home appliances like refrigerators, air conditions, etc. It may act as a DHCP (Dynamic Host Configuration Protocol) server [11] which assigns IP addresses to devices and as DNS server, which translates domain names to the numerical IP addresses needed for locating and identifying computer services and devices. The router may also include a firewall for the protection of the home network and a NAT (Network Address Translation) router which converts a local and internal IP address for an internal host into a global and visible IP address on the Internet.

Although the majority of IoT devices are using WLAN due to its simplicity and efficiency there are currently many home devices that due to weak security and high power consumption do not use Wireless LAN due but other wireless technologies such as the electricity meter and the smart home security system.

- **The electricity meter:** A smart meter is an electronic device that records consumption of electric energy and communicates the information to the electricity supplier for monitoring and billing. Smart meters typically record energy hourly or more frequently, and report at least daily. Smart meters enable two-way communication between the meter and the central system. Such an advanced metering infrastructure (AMI) differs from automatic meter reading (AMR) in which it enables two-way communication between the meter and the supplier. Generally, the electricity supplier wants to have an isolated and secure connection between the meter and the central to avoid any tampering of the meter. Communications from the meter to the network may be wireless, or via fixed wired connections such as power line carrier (PLC). Wireless communication options in common use include M2M cellular communications, wireless ad hoc networks over WLAN, wireless mesh networks, low power long range wireless (LORA), ZigBee (low power, low data rate wireless), and Wi-SUN (Smart Utility Networks).
- **The smart home security system**: consists usually of a control panel and a series of security devices such as door locks, garage door openers, indoor and outdoor surveillance cameras, lights, sirens, smoke/CO detectors, water sensors, etc. Recent control panels have the ability to connect themselves to the home wireless LAN but in order to ensure 99,99% availability, the communication of the control panel with the security company is usually realised by an M2M cellular subscription with a mobile operator. Home security devices are mostly simple and low energy sensors like smoke/CO detectors, proximity sensors, motion detector, etc. and the usage of wireless LAN will drain all their batteries in a short time. For more optimal energy usage these devices use other wireless protocols which consume at least 30% less energy than wireless LAN such as Zigbee, Z-wave, Bluetooth, Bluetooth Low Energy, or even proprietary mesh protocol.

The demand of a new wireless Home Networking capable of supporting all heterogeneous home devices, especially the simple ones and the secured ones is getting more and more urgent.

III. RELATED WORKS

A. Aggregated LTE WLAN Radio Access

Mobile device's simultaneous connections to both 4G and WLAN has been implemented and documented by 3GPP. The most dominant technologies are LWA (LTE-WLAN Aggregation) and LWIP (LTE-WLAN radio-level integration using IP security tunnels). Both approaches use different flow control algorithms, stimulating more efficient unlicensed spectrum utilization. According to analysis in [12], the *"LWA substantially outperforms LWIP"*. Unlike LWIP or S2b [13], the LWA allows splitting a single bearer (or a single IP flow) at a sub-bearer level, while taking into consideration channel conditions. This allows all applications to use both the mobile network and the WLAN access links simultaneously without any application-level enhancements, thus providing significant performance gains due to the offloading [14].

Independently of the two mentioned approaches, there are two models of establishing a coupled WiFi-4G/5G access, namely non-collocated and collocated models. In the non-collocated model, the existing WLAN architecture in the infrastructure can be used to integrate with the mobile network (Figure 2) and the eNB is connected with the WLAN AP through the WLAN Termination point (WT) via the Xw interface [15]; however, the collocated approach would be more suitable for home deployments in which case the eNB is tightly integrated with the WLAN access into a same device.

Despite the availability of the aggregated wireless access throughout the years, there is still no definite use-case in terms of 5G integration for smart homes and smart cities. In order to offer connectivity of the smart home IoT devices to the local or regional cloud, it is necessary to establish a possibility of accessing the home network via already implemented means, such as the local WLAN home network. For this purpose, the solution not only needs to provide a feasible wireless access but also suitable identification and authentication of the same.

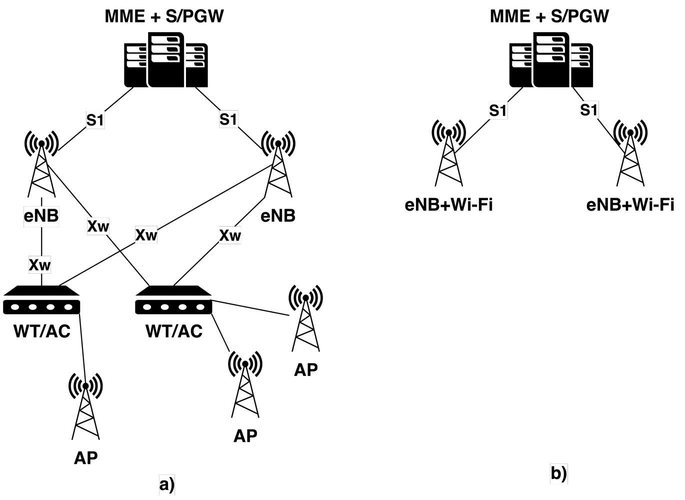

Figure 2. a) Non-Collocated vs b) Collocated deployment models

B. Femtocell

The concept of a small cell in mobile networks contains the model of deployment called "femtocell", i.e. ultra-small cell, which is realised by a small, low-power cellular base station, typically designed for use in a home or small business. This indoor deployment concept is intended to accommodate only couple of users per cell, while providing sufficient quality of service and user experience. The femtocell e-NodeB is also called HeNB, which stands for Home e-NodeB, and the architectural concept is specified according to the 3GPP TR 23.830 specification in Release 9 [16].

The Femtocells are used as relaying points in mobile technologies, which are sought to provide extended coverage in areas where access is limited due to signal impairments or lack of mobile infrastructure. The relaying not only enhances the coverage, but also the capacity of the network by establishing more resources for more consequent users [17].

As described above, the Femtocells are merely a small indoor mobile base stations and for our Small Home solution, they need to be extended to include also a WLAN home router as well. Furthermore, it has to be connected to two 5G network slices in order to accommodate two different types of devices with different Quality of Service demands.

IV. 5G MOBILE NETWORK SLICING CONCEPT

Originally the mobile network is aiming at providing connectivity for mobile phones which are on the move in the outside. With technology advances mobile phones are migrating to 3G and 4G mobile networks and leaving the 2G mobile networks to M2M devices which uses the uplink only at predefined time intervals to transmit a small amount of data to their cloud server.

As the successor of 4G, 5G mobile system [18] is well known for its superiority in terms of performance, coverage and quality of service and the promise of enhanced mobile broadband (eMBB) with higher data speed and the support of a wide range of services and application ranging from massive machine-type communications (mMTC) and ultra-reliable and low-latency communications (URLLC). To achieve this challenging objective the concept of network slicing is presented as the ultimate solution which will be clarified in the coming section.

To understand the network slicing concept let us start with a short introduction of the 5G mobile system architecture.

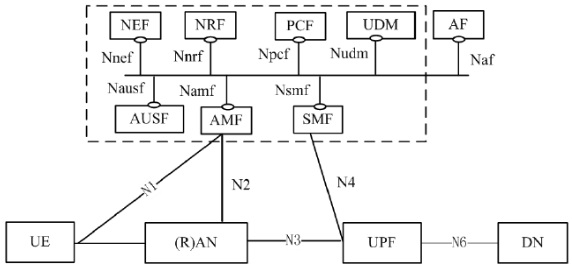

Figure 3. The 5G Reference Architecture (Courtesy of 3GPP)

As shown in Figure 3 the 5G Reference Architecture differs with the 4G architecture not only in their different Network Functions [19] but also in the separation of the User plane and Control plane.

The User plane consists of the following Network Functions:

- **UE** (User Equipment): is the user's mobile phone.
- **(R)AN** (Radio Access Network): is the Access Network Function which provides connectivity to the mobile phone.
- **UPF** (User Plane Function): handles the user plane traffic, e.g., traffic routing & forwarding, traffic inspection and usage reporting. It can be deployed in various configurations and locations depending on the service type.
- **DN** (Data Network): represents operator services, Internet access or 3rd party services.

The User plane consists of the following Network Functions:

- **AMF** (Access and Mobility Management Function): performs access control, mobility control and transparent proxy for routing SM messages.
- **AUSF** (Authentication Server Function): provides authentication functions.
- **UDM** (Unified Data Management): stores subscriber data and profiles. It has an equivalent role as HSS in 4G but will be used for both fixed and mobile access in 5G core.
- **SMF** (Session Management Function): sets up and manages the PDU session according to network policy.
- **NSSF** (Network Slice Selection Function): selects the *Network Slice Instance* (NSI), determines the allowed *network slice selection assistance information* (NSSAI) and AMF set to serve the UE.
- **NEF** (Network Exposure Function): exposes the services and capabilities provided by the 3GPP network functions.
- **NRF** (NF Repository Function): maintains NF profiles and supports service discovery.

- **PCF** (Policy Control function): provides a policy framework incorporating network slicing, roaming and mobility management and has an equivalent role as PCRF in 4G.**AF** (Application Function): interacts with the 3GPP Core Network (CN) to provide services.

Currently, there is no consensus on what a network slice is and how it can be realized. In fact, while the 3rd Generation Partnership Project (3GPP) [20] provides a more network-focused definition stating that "network slices may differ for supported features and network functions optimisations", the 5G Infrastructure Public Private Partnership (5G PPP) adopts a business oriented view mandating that "network slice is a composition of adequately configured network functions, network applications, and the underlying cloud infrastructure (physical, virtual or even emulated resources, RAN resources etc.), which are bundled together to meet the requirements of a specific use case, e.g., bandwidth, latency, processing, and resiliency, coupled with a business purpose" [21].

In this paper we use the 5G PPP's definition that allows the support of a variety of devices. To obtain a wireless Home Networking capable of supporting a broad range of devices the 5G network slicing concept is adopted to establish a Smart Home Network Slice.

V. THE 5G4IOT SMART HOME SOLUTION

As there will be both WLAN and mobile network devices in the future home our Smart Home solution will have to able to support both types of devices. As shown in Figure 4, the 5G4IoT Smart Home can be typically realised by two network slices as follows:

- **mMTC (massive Machine Type Communication) Network Slice:** OpenAirInterface deployment of a Core Network and eNB base station, powered by USRP B210 software-radio [22] at Band 3 – 1.8GHz and Band 7 – 2.6GHz (mobile network)
- **WLAN Network Slice:** LWIP deployment of a containerized WLAN function for dual-connectivity architecture to multiple base stations simultaneously, powered by the same USRP B210 software-radio at 2.4GHz

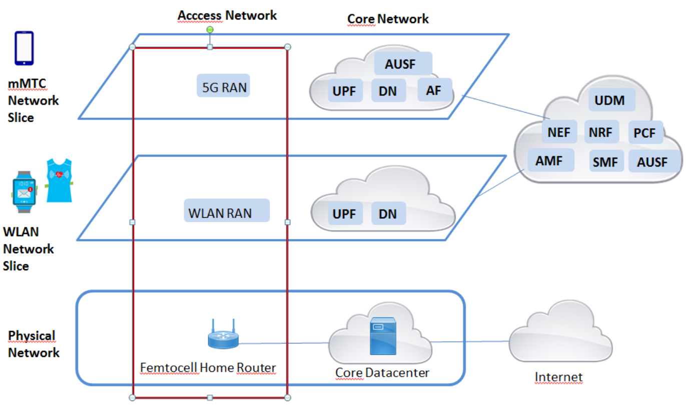

Figure 4. Architecture of the 5G4IoT Smart Home Solution

As shown in Figure 5, the femtocell home router offers both WLAN and 4G/5G connectivity in the home where the eNB macro-cell can struggle to reach the indoor devices. In this case, the backhaul link to the service provider is a fibre or cable line, which is routed through proprietary gateway. However, the backbone link can also be 5G fixed wireless if necessity arises, or if the mobile operator does not have a terrestrial deployment solution in the particular area.

Additionally, the operator can offer local cloud services for specific applications and thus the users can access these with minimal latency and optimal performance. Such applications are usually smart-home related, as for the home appliances so as for the electric cars, gadgets or various contrivances.

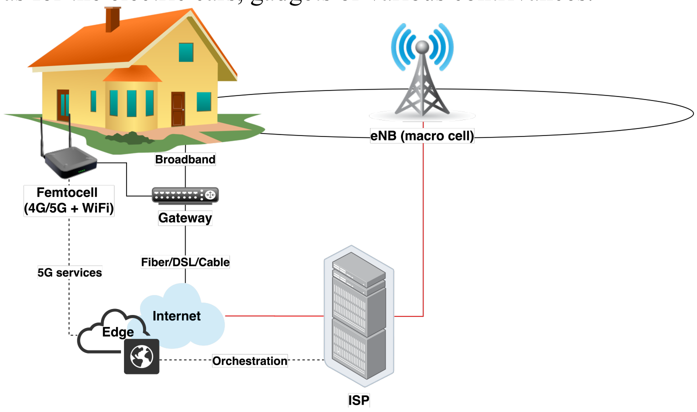

Figure 5. Femtocell architecture example for smart home deployments

The femtocell home router should be able to operate as a multi-purpose device, namely having the following characteristics:

- Interfaces for fibre/Ethernet networking in order to connect to any external network gateway provided by the service provider
- Wireless capability for both Wi-Fi and 4G/5G by using multiband antennas, as well as NBIoT (NarrowBand IoT)
- Utilization of software-defined radio entities, i.e. being able to work independently on a generic Linux PC or as a standalone device, while connecting to the operator's core network
- Capability to communicate with AAA server (EAP-AKA for the WLAN and the DIAMETER authentication service in the core network of the 4G/5G)
- Capability to implement routing protocols such as BGP, OSPF, AODV etc.

VI. IMPLEMENTING THE 5G4IOT SMART HOME

As shown in Figure 6 the proposed Smart Home architecture can be realised by combining network slicing with a femtocell home router implemented by a generic computer running an integrated containerized LWIP instance in collocated mode with an eNB . The mobile operator has the opportunity to control the resources assigned to each slice i.e. mMTC network slice and WLAN slice by defining policies for the particular containers in which the VNF (Virtual Network Function) is running for the specific entity, i.e. the eNB instance or the LWIP instance.

At the Oslo Metropolitan University, the 5G4IoT lab relies on the deployed OpenStack cloud infrastructure, where the majority of mobile VNFs are instantiated [23]. The major technology used for virtualization is the Docker container technology. In the specific use-case, the containers allow the possibility for immutable infrastructure, as well as flexibility with instantiation, repeated deployments, rolling updates through continuous integration pipelines and most-importantly, simplicity.

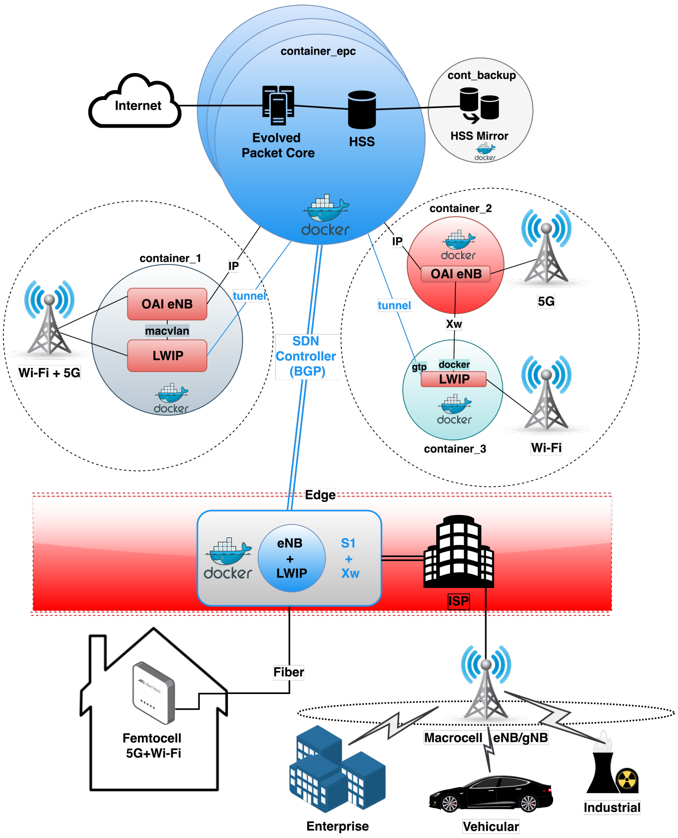

Figure 6. Secure 5G4IoT Lab infrastructure reference architecture

This type of deployment is very appropriate for home femtocell considerations, where the subscriber can have all the necessary virtual network functions provided by a single deviceIthe case of the slice on right in Figure 6, in non-collocated manner, an existing enterprise or a factory can utilize the WLAN infrastructure it has to merge the policies designated for the 5G network. This way, every device that connects to the Wi-Fi slice for Industrial, Vehicular or Enterprise can enjoy the same policies defined for that particular slice (Quality of Service, accessibility, network-related operations, routing etc.). A good example is a Tesla car, which includes a 4G/5G interface to access the mobile networks, as well as WLAN in order to download updates when parked in the home garage. The identity provided for the car will belong to the same slice when the user decides to connect the car to the home WLAN Femtocell router. At the same time, the VNF instance running in the Docker container at the local Edge cloud will have the same policies defined by the service provider and the user will not notice any difference by connecting the car to the 4G/5G network in the city or the WLAN at home, with the difference that through the WLAN the car can download updates without incurring traffic fees designated with the mobile network plan, while simultaneously preserving the same identity in the network. In order for this to be possible, the 5G4IoT lab has introduced a secure identity federation that can manage the identities of various devices connecting to the network [24][25].

In rural areas, where the mobile coverage can be limited, the inhabitants mostly rely on the provided broadband link or connectivity via satellite. In the case where the macro cell eNB (as in Figure 6) does not have the ability to provide suitable signal strength to some places, the user can have the car or any other IoT device access the mobile infrastructure via the Femtocell Smart-Home deployment, allowing for an excellent connectivity through 4G/5G and WLAN in unlicensed spectrum.

In this case, providing a femtocell home router which tightly integrates WLAN with 5G can prove to be a very efficient way of allowing additional devices to load-balance in case a higher bandwidth is needed, to simply access the network due to their inability to contain a 5G interface but only WLAN, or even failover in case one of the links fails.

VII. Discussion

While the non-collocated type of access in the femtocell architecture can prove very practical and cost-effective, a device that is intended to provide both 4G/5G and WLAN processing should be FPGA-based. This strict requirement comes from the fact that the sampling rates required for the 802.11 standards as well as the 3GPP access types are very high and devices without proper performance would be unable to meet the demands for providing such sampling rates. Another requirement for achieving proper QoS is the backhaul access, which needs to be adequate enough in order for the femtocell to deliver good user experience. Many operators do not provide end-to-end fibre connectivity, especially to rural areas, and in this case, the only solution for backbone connectivity would be the fixed wireless 5G macro-cell base station, or satellite link in some cases. Therefore, these solutions may prove more expensive for the end user that lives in a remote area.

VIII. Conclusions

As specified today 5G can only support devices with 5G access and this may be difficult for ensuring a successful 5G Smart Home solution. To be successful a Smart Home solution should have the ability to support other existing wireless technology such as WLAN. Zigbee, Low Energy Bluetooth, Z-Wave, etc. Our 5G Smart Home solution meets this requirement by combining the 5G network slicing with a dual 5G and WLAN home router. A prototype providing two network slices, one slice for 5G mMTC devices and one for WLAN devices has been successfully implemented at the Secure 5G4IoT lab. As future works, it may be interesting to introduce additional 5G network slices to support other 5G devices. An important work shall be the calibration and benchmarking of the femtocell home router. Last but not least will be a field trial in which the proposed Smart Home solution is deployed in a real home environment with real IoT devices both 5G access and WLAN.

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