MiWEBA

Millimetre-**W**ave **E**volution for **B**ackhaul and **A**ccess

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Abstract

This report describes scenarios and use cases of the MiWEBA project dealing with mm-wave overlay heterogeneous network (HetNet) in which mm-wave ultra-broadband phantom cells are integrated into conventional cellular networks to fulfill 1000 time network capacity increase in the next 10 years with constant power consumption and infrastructure deployment cost. Multi-Technology HetNet architectures including mm-wave radio links in front/backhaul and access scenarios are the key technical challenges of the MiWEBA project. The D1.1 deliverable describes MiWEBA scenarios including key assumptions in relation with innovative architectures integrating mm-wave phantom cells in the 4G and 5G cellular networks, advanced C-U plane separation potentially using independent air interfaces, multi-technology link adaptation techniques and Radio Resource Management mapped upon front/bakhaul and access scenarios. Use cases are then detailed providing environment scenarios, applications and services. The document is composed of three parts describing MiWEBA architectures, scenarios and use cases respectively.

Keywords

mm-wave radio link, overlay HETNET, C-U plane separation, Multi-RAT

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Abbreviations

Acronym	Description
AB	Advisory Board
AFO	Administrative Financial Office
C-RAN	cloud RAN
BBU	base band unit
c-plane	control plane
CSI	channel state information
CoMP	Coordinated Multi-Point transmission
EU	European Union
FST	Fast Session Transfer
HARQ	hybrid automatic repeat request
ICD	Inter-Cell Distance
HetNet	Heterogeneous Network
LA	Link Adaptation
MIMO	multiple-input multiple- output
MIM	Multiple Interface Management
mm-wave	millimetre-wave
MMR	Mobile Multi-hop Relay stations
MTCN	Multi-Technology Cellular Networks
MTLA	Multi-Technology Link Adaptation
RRH	Remote Radio Head
RRU	Remote Radio Unit
RRM	Radio Resource Management
RS	Relay Station
RPS	Reference Position Signal
SRD	Short Range Distance
UE	user terminal (user equipment)
u-plane	user plane
PoC	Proof of Concept
UWB	Ultra Wide Band

JP	Japan

Executive Summary

This public report details the architectures, scenarios and use cases for the MiWEBA project that will guide the analysis of the specific technical solutions developed by the different work packages. In the MiWEBA project, the major challenge is to design and optimize overlay heterogeneous networks (HetNet) in which mm-wave ultra-broadband phantom cells are integrated into conventional cellular networks. The goal is to fulfill 1000 time network capacity increase in the next 10 years with constant power consumption and infrastructure deployment cost as announced for 5G networks. For that purpose, innovative MTCN are designed including mm-wave systems for access and backhauling fronthauling.

Architectures and scenarios are derived from technical challenges of the MiWEBA project, detailing key assumptions of the project split into access and front-haul backhaul scenarios. Mm-wave component integration into Multi-Technology HetNets involve dedicated technical challenges based on the functional separation of control and data planes upon independent radio interfaces including mm-wave interfaces and Multiple Interface Management using novel Multi-Technology Link Adaptation metrics and advanced cross layer mechanisms with limited latency and high scalability.. The optimization of such Multi-Technology architectures will be optimized using traffic models and radio engineering tool extensions. Radio Resource Management is also one of MiWEBA key technical challenge where unlicensed and licensed frequency bands are combined together to build MTCN. The outdoor extensions of mm-wave interfaces initially designed for indoor and short range applications involve a proper challenge related to mm-wave propagation modeling and link budget assessments.

Scenarios are split into access and backhaul/fronthaul scenarios with three access sub-scenarios (indoor, outdoor, Multi-Technology Het Net scenarios) and two backhaul/front haut sub-scenarios covering P2P and PMP architectures and Mobile Multi-hop Relay Node schemes.

Use cases are derived from scenarios and provide a practical description of deployment scenarios detailing environments and applications. Six non exhaustive use cases have been determinated to illustrate Multi-Technology HetNet applications.

1 Introduction

The use of mm-waves in the access, backhauling and fronthauling of future wireless networks represent the big technical challenge of the MiWEBA project. Different from previous research on this topic that has focused on basic technology issues including hardware, antennas and transmission techniques; in MiWEBA, the system level perspective plays a fundamental role for understanding how mm-waves technologies can be integrated into a larger picture that includes modern mobile cellular networks with a large set of heterogeneous technologies and network layouts. Therefore, it is particularly important to define the relevant scenarios for the project and how different system components can be integrated together and evaluated during the project for meeting the characteristics of the considered scenarios.

This document presents the scenarios and use cases for the MiWEBA project that then will guide the analysis of the specific technical solutions developed by the different work packages.

In the scenarios presented in the following sections, the focus is on the network layouts, use and deployment of heterogeneous technologies, radio engineering and types of areas covered. As for network layouts, the document considers possible instantiations of the general system architecture that is based on the functional separation of control and data planes at the radio interface and Multiple Interface Management combined with an optimized Multi-Technology architecture deployment. This allows using small cells based on mm-wave technologies mainly for data traffic with light control overhead and take advantage of the control functions and signaling messages provided by other technologies for example. Multiple Interface Management using dedicated metrics to perform Link Adaptation processing will prove advantages of mm-wave phantom cells in Multi-Technology HetNet architectures. These architectures and the densification network will be optimized by mapping these metrics into a radio engineering tool which will explicitly take into account environment topologies. This deliverable presents the main reference technologies for the project and how they can be integrated to create scenarios that are more promising for their potential impact on applications and user quality of experience. Since, as in any wireless network, the design and deployment are driven by the type of areas to be covered and the expected traffic distribution; the scenarios are classified based on the coverage areas and a set of specific indoor and outdoor areas.

For the complete scenario description, traffic and channel models to be used for new mm-wave systems are among the objectives of MiWEBA. In particular, WP4 will analyze Radio Resource Management strategies and define appropriate traffic models for their evaluation, while WP5 will define channel models able to describe propagation of mm-waves in both indoor and outdoor environments. Therefore, the D1.1 deliverable will focus on the definition of a set of requirements for the traffic and propagation models.

As for the use cases, the approach that has been selected is that of focusing on a generic use case description close to the environment deployment and appropriate applications and services provided by the telecommunication operators.

1.1 Key Technical Challenges

The increasing data volume and data rates of high QoS services involve new emerging cellular networks resorting from convergent Heterogeneous Networks (HetNet) combining different technologies and interfaces. Usual key technical challenges of the future 5G systems are to 1000 time increase the capacity in the next 10 years by considering spectrum efficiency, spectrum usage extension, interference cancellation, new waveforms, with a constant network power consumption and deployment cost. Different approaches are being pursued to increase the overall network capacity and the maximum supportable data rate per user.

Spectrum extension covering licensed and unlicensed bands requiring Multiple Interface Management (MIM) between cellular and Wi-Fi networks and convergent networks are one of the promising solutions to fulfill 5G cellular network requirements to be addressed in the MiWEBA project. Therefore, new spectrum should be utilized preferably in higher frequency bands, e.g. mm-wave bands or beyond for Multi-Technology cooperative networks. The 5 GHz and 60 GHz ISM bands will be combined with the cellular spectrum in order to generate Multi-Technology Cellular Networks (MTCN).

The outdoor extension of indoor, Short Range Distance (SRD) and other wireless technologies is one of key point supported in the MIWEBA project by considering system parameters, RF transposition of indoor systems into high frequency bands with regards with power, frequency regulations and first link budget analysis.

The increased capacity per cell makes high capacity backhaul solutions between radio access points and the core network a prerequisite, Cloud-RAN architectures integrating alternative wireless and wired components will be optimized turned towards the best trade-off between capacity and coverage.

D2D links between user terminals and RRM will be addressed in the WP4.

Following technical challenges will be then considered in MiWEBA scenarios:

- Frequency and power regulations.
- New waveforms focused on spatial focusing techniques and scalable beamforming to increase radio coverage and reduce interference.
- Multi-Technology Link Adaptation (MTLA) techniques and Multiple Interface Management (MIM) processing in order to optimize radio link of every individual users and their integration into system level assessments.
- Cross layer mechanisms dedicated to MTCN considering Control Plane and User Plane adapted to Multiple Interface Management.
- Advanced C-U plane separation architectures using different technologies and spectrum use in order to limit the global network power consumption whilst improving the global throughput.
- Network densification by adding small cells operating in complementary frequency bands using independent air interface to allow better spatial reuse of radio resources and Inter-Cell Distance optimization in multi-Technology HetNets.
- Radio engineering tool extension integrating link budget and Link Adaptation metrics to optimize ICD, technology selection and MTCN in accordance with environment topologies, targeted QoS, transmit power level and radio coverage.

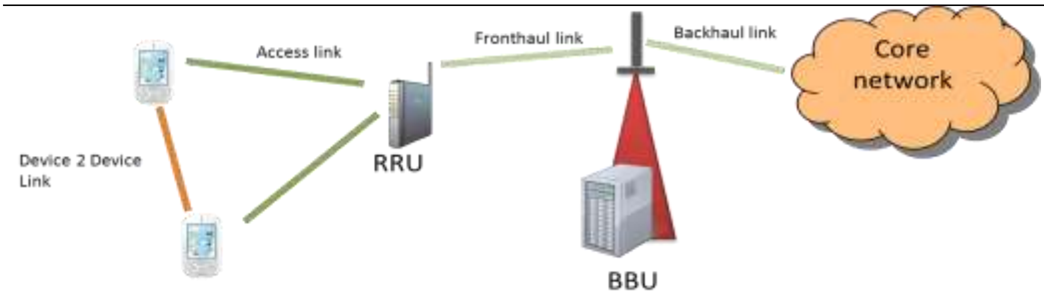

Figure 1.1: MiWEBA scenarios

Following these key assumptions, MiWEBA scenarios are designed and mapped into 2 classes of scenarios: Access Network and Backhaul scenarios with proper indoor and outdoor specifications.

1.2 Structure of the document

In Section 2 we give an overview of the network architecture as considered by the project to point out how scenarios are specific implementations of the general architecture. In Section 3.1, we focus on access scenarios for indoor and outdoor areas and explain how multiple technologies are used in the access interface of the system. In Section 3.2, the focus is on backhauling and fronthauling with point-to-point (P2P) and point-to-multipoint (P2M) links, possible use of relay nodes and heterogeneous technologies for the different segments. Section 3.3 is dedicated to traffic and channel models and the requirements for the work to be done in WP4 and WP5. Section 3.4 focuses on use cases related to scenarios, environments and applications.

2 Overview of network architectures

2.1.1 Access Network architectures

The network deployment solution that is commonly considered most suitable for capacity expansion in mobile networks is based on massive use of small cells with sizes ranging from few tens of meters up to 100-300 meters, which are added into the coverage area of traditional cellular macro cells. The resulting network structure is usually indicated as Heterogeneous Network (HetNet) where a single technology is considered and several RF bands (2GHz and 3.5 GHz) are envisioned to greatly increase the data capacity in dense urban areas characterized by traffic hot spots [3GPP_1,12] (Figure 2.1).

The heterogeneity in the cell architecture can be extended from cell size to multiple access technologies and spectrum portions as well. Indeed, the difficulties to define a wireless technology able to fit all application needs and the regulations in the use of different spectrum segments have led to a proliferation of technologies that are supported by modern smart user devices and that can be extended to small cell deployment.

Moreover, the evolution in the radio transmission techniques at extremely high frequency (above 30 GHz) with mm-waves makes the large amount of bandwidth of those spectrum portions available in the near future for new access technologies able to cover areas of up to a few tens of meters with transmission rates of 10 Gb/s or more. This is the key idea of MiWEBA project which aims at studying the fundamental technology at the basis of this evolution in wireless access, fronthaul and backhaul as

well as to address the architectural issues that are relevant for their integration into mobile access systems.

The concept of macro cell offloading to small cells that allow capacity increase can be extended even further considering the possibility of device to device (D2D) direct communication that is particular interesting in application scenarios characterized by information dissemination where the heterogeneity is brought to the extreme by adding non-access links to the system architecture.

However, in this multi-technology heterogeneous network environment, the management of radio resources and multiple Interfaces are challenging tasks mainly because the cell and technology selection depends on mobile positions, environment topologies and handover mechanisms in relation with small cell sizes and Inter-Cell Distance (ICD). For example, even in the simpler case of a homogeneous technology with LTE base stations, controlling the coverage area of small cells is not easy. Since cell selection is based on the strongest reference signal, only limited adjustment is allowed to the network through the use of an offset parameter for privileging small cells. Each cell is an almost independent element of the network architecture with its own control plane and typically large signaling overhead for the transmission of system information, terminal associations, radio resource assignments, and mobility management messages. Cell selection procedure can become even more limiting with multiple technologies and a large number of radio channels since the terminal can have reduced capabilities to switch between technologies in short time to discover available cells scanning the spectrum. With high frequencies and mm-waves in particular, the short transmission range, the harsh propagation impairments, and the use of directive transmissions make the task of discovering cells and accessing them very difficult.

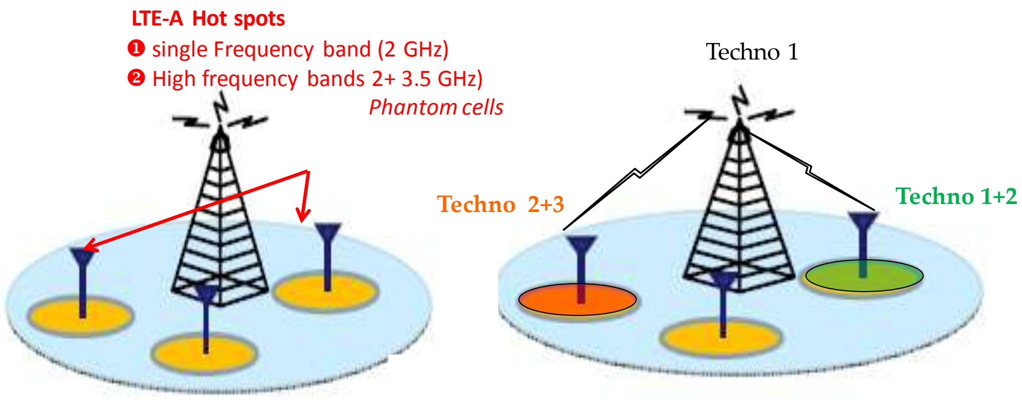

Figure 2.1: HetNet and Multi-Techno HetNet architectures

Another critical aspect is the energy consumption that is becoming a major concern for wireless access. This is the most energy hungry portion of the network and can have not only a negative impact on the environment but also on the operational costs of operators. The power profile of macro and small cells is basically almost independent from traffic load and dominated by the need to keep the signaling plane always active for network accessibility. Moreover, the need to guarantee full coverage in the service area at any time greatly limits the possibility to put in sleep mode some of the base stations and makes the energy consumption growing at the same rate of the capacity injected in the network with new small cells.

Recently, new mobile network architectures have been proposed to overcome the limitations of traditional HetNets considering a separation of the data and control planes

at the radio access interface of wireless networks (Figure 2.2). The basic idea is to enable mobile terminals to receive system information, issue access requests to a base station and getting assigned radio resources for high-rate data transmission at a different base station. Signaling and data services can be provided by specialized base stations or implemented as separated and independent services into the same physical equipment. In the case of HetNets a possible approach is to have the macro base station providing the signaling service for the whole area and the small cells specialized in data resources for high-rate transmission with a light control overhead. The idea of data/control split was initially proposed in the3GPP by NTT Docomo [3GPP_1,12] and by the project Beyond Green Cellular Generation (BCG^2) of the GreenTouch consortium [GreenTouch] for improving the network energy efficiency. Similar approaches aimed at a more flexible resource management and signaling overhead reduction have been proposed the study group of 3GGP on “New Carrier Type”.

The main advantage of separation is the removal of the constraint for which radio resources for data transmission are assigned by the same base station used for accessing the service, which is autonomously selected by user terminals. In terms of energy efficiency, this is a big advantage since it allows to activate small cells only when needed, with an “on demand” data coverage, while providing everywhere and anytime service accessibility through the full coverage signaling function. More in general, the additional flexibility in resource assignment allows to shift the control of access selection from mobile terminals to a logical network entity and to optimize the resource assignment with a larger view on several parameters, such as the technologies available in the area and their support in the mobile terminal, the load of different cells, the quality of experience required, the user profile, the mix of active applications, the operator user management policies, etc. The separate signaling function provided by the access infrastructure can be also used to configure and control D2D links that would be much more difficult to discover and activate in a distributed scenario without an external control entity.

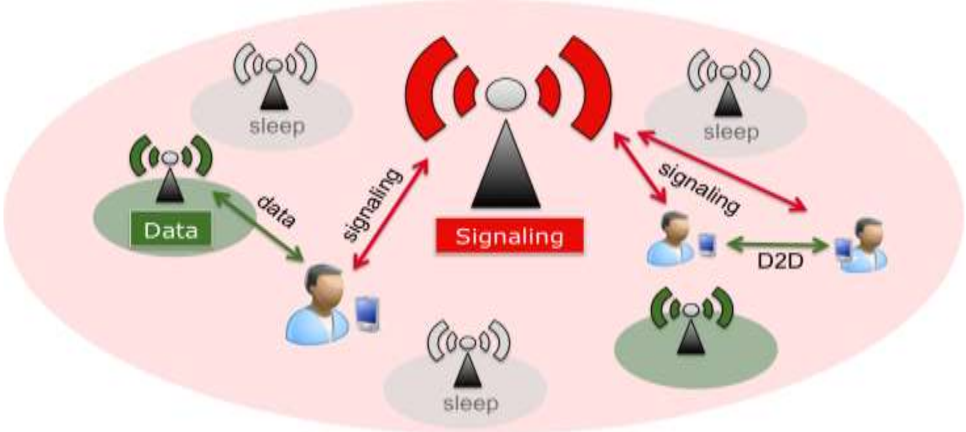

Figure 2.2 : System architecture with separation of control and data planes at the wireless access.

Another critical point is to dynamically select the interface transmission for each radio link involving multi-technology base station and terminals and fast Link Adaptation (LA) mechanisms. The global Multi-Technology architecture covering interface selection in small cells, Inter-cell distance definition between Multi-Technology cells and Multiple Interface Management mechanisms are key points of the Multi-RAT architectures. For that purpose, dedicated link adaptation metrics will be designed to perform interface selection and cross layer mechanisms will be designed to implement MIM mechanisms derived from ICT-FP7 OMEGA project [OMEG2+11], standardized

Fast Session Transfer [FST,10] and ANDSF [3GPP_AND,13] mechanisms (see section 3.1.3). Additionally, Radio engineering tool will be exploited to explicitly take into account real topologies in dynamic interface selection, ICD adjustment and MTCN architecture deployment.

2.1.2 Role of RRM

The main functions of separated signaling (control plane) are mobility management & resource control. The mobility management is usually performed with RPS (Reference Position Signal) to estimate relative position of UEs with respect to macro or small BSs. In near future, GPS (global positioning system) will also be used to enhance the accuracy of mobility management that has not been standardized in 3GPP yet. The resource control manages radio resources of UEs such as cell and technology selection. Resource control of the small BSs should also be performed at the same time to supply on-demand data coverage against mobile UEs. The resource control of small BSs is also important to reduce energy consumption by activating small BSs on demand. The resource control for UEs include wake up (activation), cell and technology selection, and handover among macro BS and small BSs. On the other hand, the resource control for small base stations includes BS dormancy, antenna beam control, channel selection, and transmit power control. Especially, the control of antenna tilt angle (vertical plane) and antenna sector angle (horizontal plane) are very important to realize dynamic cell structuring to track mobile UEs and transfer radio resources from sparse areas to dense hotspots. This concept is also referred as phantom cell or ghost cell in 3GPP standard. If coordination between different small BSs is available, interference control among small BSs can be performed such as coordinated scheduling and/or beamforming. As an extreme case, all small BSs surrounding hotspot can perform joint transmission (JT) against UEs in the hotspot to increase system rate in collaboration with dynamic coverage control of small BSs. By introducing such mobility and resource management scheme, average system rate per consumed power can be maximized.

2.1.3 Backhaul/fronthaul architectures

Backhaul and Fronthaul connections refer to intermediate links between the core network and the small sub-networks attached to a macro-cell usually a Base Band Unit (BBU) and the connection between a BBU a Radio Remote Unit (RRU) respectively. The basic difference between backhaul and fronthaul links is the position of the logical split in the network architecture.

The backhaul link usually transports the pure user data (e.g. IP packets), the fronthaul link often transports already encoded and preprocessed digital signals prepared for the access link. As a consequence this leads to different requirements on the latency, robustness and bandwidth of these links. Fronthaul may be assimilated to access link with limited mobility. Relay networks are integrated in the Fronthaul and Backhaul scenarios as envisioned in the IEEE802.16 {m,j} and 3GPP standards [IEEE802.16j,09] .

Another important element of the MiWEBA basic architecture is the possible separation of radio units for RF signal transmission on the access interface, named Remote Radio Heads (RRHs), and the base band processing units (BBUs) that are responsible for all the signal processing operated for transmission and reception. The architecture configuration where BBUs are located into a central site for a set of RRHs is usually referred to as Centralized Radio Access Network (C-RAN). The links connecting RRHs and BBUs are indicated as fronthauling and transport with no processing the radio signal to the BBUs. Then the BBUs are connected to the core network through the usual backhauling links.

Both for fronthauling and backhauling links, mm-wave technologies are promising candidates as an alternative to fiber due to the high capacity available and deployment scalability.

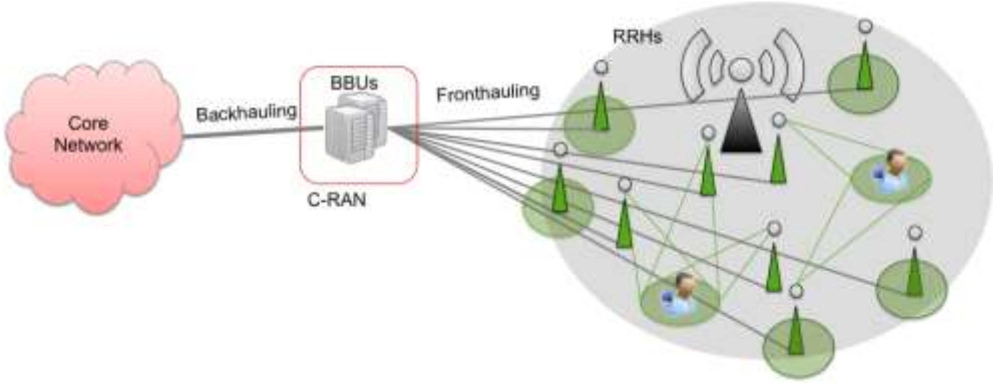

Figure 2.3 : System architecture with separation of RRHs and BBUs for mm-wave fronthauling and backhauling links.

Several sub-scenarios are envisioned in Front/backhaul architectures integrating mobile terminals in dense environments and Mobile Multi-Hop Relay (MMR) stations.

2.1.3.1 Cloud RAN architectures and Mobile Relay Node architectures

Cloud RAN architectures are one of the most important part of the Backhaul/Front Haul scenarios. An illustration is given on the Figure 2.4 where fiber transmissions may be replaced, in dedicated configurations, with mm-wave links in order to introduce scalability in Relay Station positions and improve link budget as well as deployment costs.

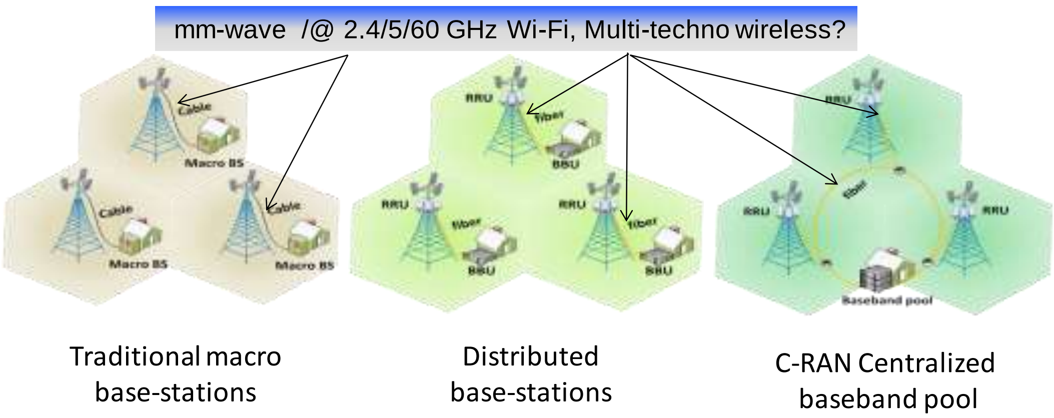

Figure 2.4: Multi-Technology Cloud-RAN topologies

By considering overall candidate air interfaces able to perform high throughput (up to several Gbit/s) in accordance with frequency and power regulations upon directive links, link budget assessments will be performed to design wireless architectures limiting infrastructure costs and offering deployment scalability.

For that purpose, microwave technologies as well as radio access technologies dedicated to access scenarios will be examined in particular the IEEE802.16e standard [802_16e,05] for medium data rates and the mm-wave IEEE802.11ad and IEEE802.15.3c [IEEE802.11ad,13][IEEE802.15.3c,09] standards for high data rates and their extension to outdoor for LOS transmissions. New emerging Wi-Fi standards and

white space technologies will be studied when the radio link between the RRU and BBU are partially obstructed.

There is currently an ongoing effort within the 3GPP and LTE-A toward the completeness of the relay specification in combining MIMO and COM'P system architectures . The IEEE 802.16j standard [IEEE802.16j,09] as a complementary standard to IEEE802.16 {e,m} standard manages Relay Stations (RS) and the connection to the access network.

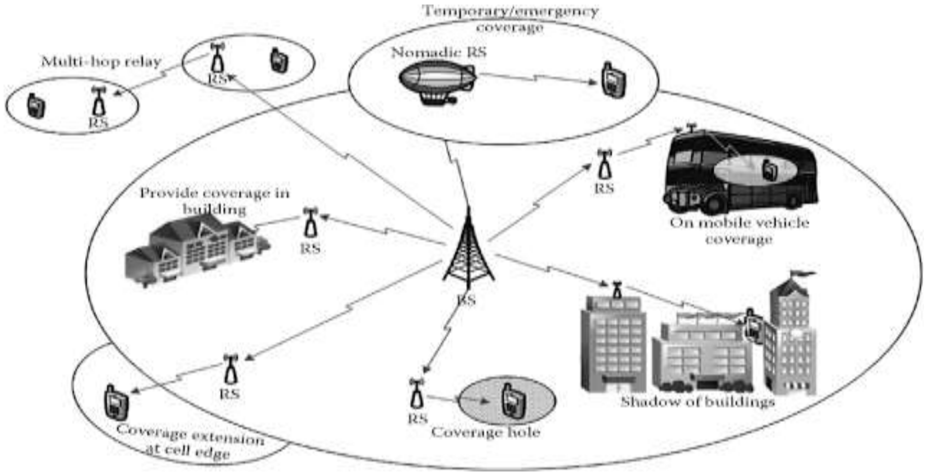

Figure 2.5: MMR architectures using COM'P and IEEE802.16j mechanisms

In IEEE802.16j MMR solutions, the BS may be replaced by a Multi-hop Relay BS (MR-BS) and one or more RS. Two synchronized networks are deployed : one dedicated to Relay Stations connections to cover middle mile and another one from each Relay Station to fulfill PMP last Mile traffic (Figure 2.6).mm-wave components will be integrated in the multiple network management.

Traffic and signaling between the SS and MR-BS are relayed by the RS thereby extending the coverage and performance of the system. Each RS is under the supervision of an MR-BS. In a more than two hop system, traffic and signaling between an access RS and MR-BS may also be relayed through intermediate RSs. The choice of radio link type depending on transport functions will be examined in the MiWEBA project integrating mm-wave components covered by Wi-Fi technologies extended to outdoor directive links and IEEE802.16 {e,m} technologies.

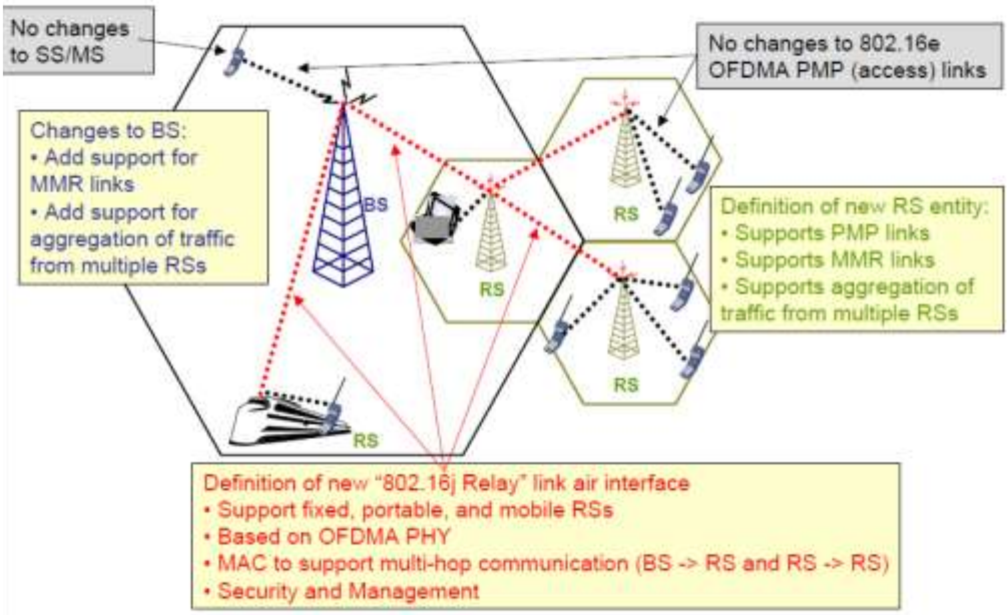

Figure 2.6: Mobile Multi-Hop Relay based on IEEE802.16 {e,m} technology

The IEEE802.16j standard PHY utilizes the OFDMA-PHY layer of the IEEE802.16e for transmission of PHY PDUs across the relay link between MR-BSs and RSs. Maximum data rates are up to 70 Mbps for each link to be shared between several MT from a RS. A dedicated frame structure compliant with the IEE802.16e is designed to build PHY frames structures compatible with IEEE802.16{e,m} PHY frames and introduces novel MAC protocols for relay processing. A tutorial [MNP,06] is available, detailing gains and deployment scenarios of MMR topologies. The IEEE802.16j standard performs MMR to increase the IEEE802.16e capacity, improve QoS and extend radio link distances in both dense and metropolitan areas.

2.1.3.2 Backhaul topologies

Depending on the scenario and requirements, different backhaul topology can be selected (see Figure 2.7). In fact the topology impacts the connectivity characteristics and the capacity between the point of presence (PoP) and the access point.

- **Point To Point (PTP):** This approach uses one or multiple links to connect the access point to the PoP. PTP links are an excellent way to establish connections between two sites and achieve high data transfer speeds, especially in the case when LOS is available and microwave / mmW radio is used. However, each link requires an antenna and a radio; hence in a dense deployment scenario, the PoP may rapidly be overcrowded. In general, it has been a good solution for macro cells, nevertheless more flexible approach are suitable for small cells.
- **Ring:** A ring topology is formed when a chain in a PTP network is closed. Due to redundancy, this solution offer higher reliability; however multiple hops may be required between a source and the destination. To improve the performance the network provider can add more links and transform the ring into a mesh.
- **Mesh:** This topology provides several redundant links to increase the system resiliency. However, nodes far way from the PoP may suffer from latency issues while nodes close to the PoP may generate capacity bottlenecks.

- **Point to Multi Point (PTMP):** In this topology a central node transmits/ receives to/from a high number of nodes. The hub shares its capacity amongst the end terminals, which result in multiplexing gain and higher efficiency in the resource utilization.

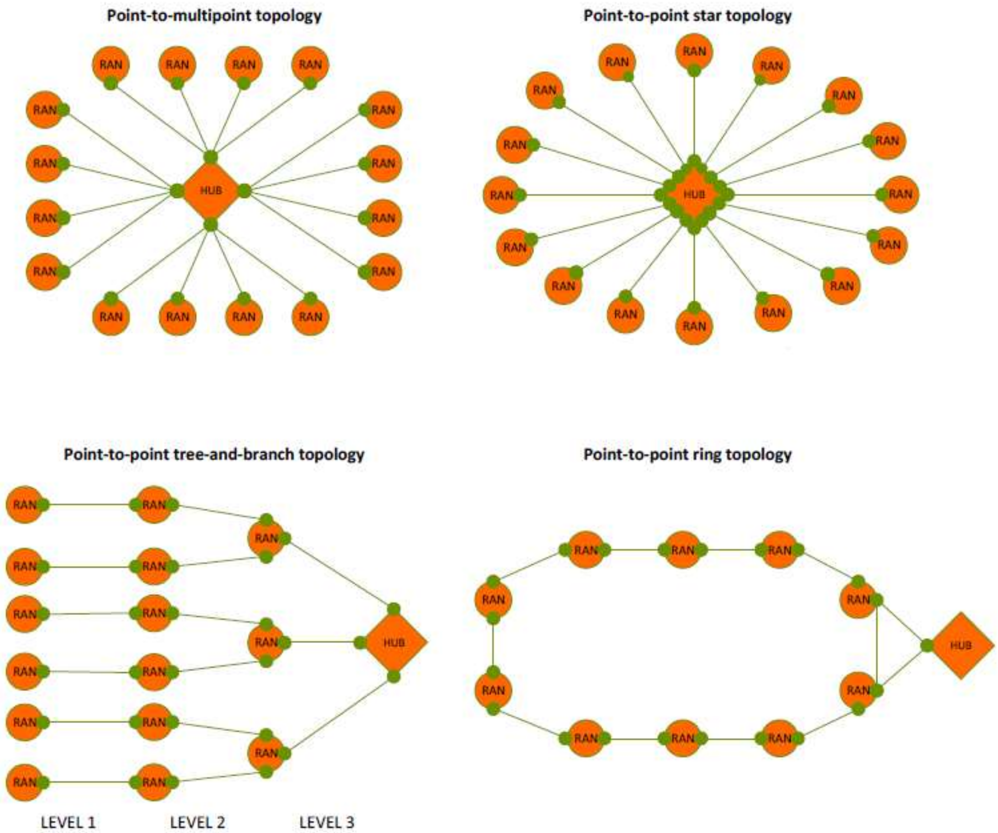

Figure 2.7: Different backhaul topology solutions [SFC 2011].

3 Reference scenarios

3.1 Access scenarios

In this section we explore the potential access scenarios the architecture proposed in MiWEBA project has to face. The type of access issues and the technical solutions to them depends on several aspects: network architecture, traffic distribution, propagation conditions and transmission techniques. However, since providing traffic and propagation modeling are tasks of the project, in this section we will make general assumptions on them so that a complete picture of the scenarios will be available after the conclusion of WP4 and WP5.

Assigning the right type and amount of access network resources to each user request can issue the basic problem of the network access. The solution of this problem can be achieved only if a solution for intermediate steps has been found. First, in order to issue a request, a user must be under the “coverage” of a network. The definition of coverage can have different flavors, but it always includes the possibility of the user to inform the network of his communication request. Second, in order to assign the right type of resources, some information on the user is required. Information on reachability,

available technologies at the device, type of traffic request, user position, and mobility models allow identifying the best combination of resources to be assigned. Third, the estimation of channel propagation conditions is necessary to identify the right amount resource to be assigned to the user. This, indeed, allows translating the assigned resources at network side into perceived quality at the user side. Finally, the type of decisions taken at each step is related to the architecture of the access network, which, in turns, depends on the traffic type, distribution and propagation conditions. The resource management is in charge of selecting the best wireless resources to serve each user according to the status of the network, therefore, it is the main actor of the network access by determining the network performance.

How users request the service and access the network is heavily influenced by the heterogeneous nature of the access network proposed in MiWEBA. There are small cells based on mm-wave technologies that are basically hot-spots providing partial coverage, while larger cells provide the full coverage with traditional cellular or Wi-Fi technologies. In the full-coverage layer, different cell sizes and capacities may be present at the same type. Therefore, selecting the best resources to be allocated in order to serve a user will not even be a trivial decision. Many aspects, like channel quality, user mobility, application requirements, and even the current network status, can influence the choice of the best base station. Heterogeneous base stations may have different roles in providing the network service: small and dense small-cells can help to support high-rate hot-zone, while large umbrella cells can be used as fallback cells when users move from a hot-zone to another.

A further degree of heterogeneity comes from the separation between control and data planes at the radio interface. This introduces the issue of designing a new user-context management system to process information about the service requested by the user. Indeed, in the MiWEBA scenario we may potentially have control and user planes provided by two different devices located at different geographical positions, which requires richer and more complex context information than in traditional cellular architectures. The use of multiple-antenna systems, which are the enabling technology for mm-wave communication, increases the complexity not only of radio access devices, e.g., antenna arrays at the same RRH to provide sharp user service, but also, of the access network management, e.g., integrated and cooperative solutions like C-RAN or CoMP. This implies, on the one hand, smarter resource management to fully exploit the potential given by the more sophisticated access devices, on the other hand, more information exchanged among access devices, thus better fronthauling/backhauling networks. Despite of the increased complexity, the c- and d-plane separation provide better tools to address all the issues coming from the heterogeneity of the radio access network, allowing to unleash the full potential of the HetNet architecture.

Mm-wave communication has additional specific issues that are added on top of the above-mentioned aspects. The traditional area coverage concept may not be always applicable since obstacles can prevent communication; the coverage for a given user could be dynamically created by rearranging the configuration of surrounding base stations in order to avoid the obstacle (which may be mobile). The use of multiple antennas requires accurate channel measurements and the initial acquisition may be delayed to make them stable. However, a separate c-plane, allowing getting information from a different channel, and a richer context about user position, predicted channel quality, service QoS and user mobility can help in reducing channel processing data and time. Mobility can have an impact on propagation, also depending on the coverage

approach (isolated hot spots, multiple cell coverage of areas, etc.); here, a fast acquisition of data channel and handovers can be sped up by a separated c-plane as well.

As a final MiWEBA opportunity, since directionality in mm-wave transmissions must be already taken into account while considering the interaction between users and networks, it is worth considering direct communications among devices, *device-to-device communication* (D2D). D2D will offload traffic from the network improving its capacity and, at the same time, could make the MiWEBA paradigm even more pervasive by including cable replacement technologies. The envisioned D2D scenario is characterized by “ad hoc” links established among users in the same room, or in limited outdoor area. The MiWEBA architecture facilitates D2D communications in two ways. First, the separated control plane facilitates the configuration of peer devices reducing the session establishment time. Second, the rich context-information used for accessing the network can be used to implement the detection algorithm for contact opportunities. The use of D2D will be basically application driven, the setup of a D2D environment is triggered by the requests of an application that is simultaneously running on the devices of a group of closed users.

3.1.1 Indoor coverage scenarios

There are basically two scenarios for indoor mm-wave communications: *isolated rooms* and *large indoor public areas*. Within these scenarios, several technologies are combined together to ensure seamless connectivity and different applications and services (3.4.3). Dedicated Multi-Technology scenarios adapted to both indoor and outdoor scenarios are addressed in the section 3.1.3.

3.1.1.1 Isolated rooms

This scenario consists of a single room, possibly large, covered with traditional cellular technologies (LTE, LTE-A) small cells or WiFi, and a number (depending on size) of mm-wave nano-cells providing full coverage of the space (Figure 3.1). The typical situation described by this scenario is an exhibition hall, an office open space, a garage or a production workshop, where devices can be user equipment or machines.

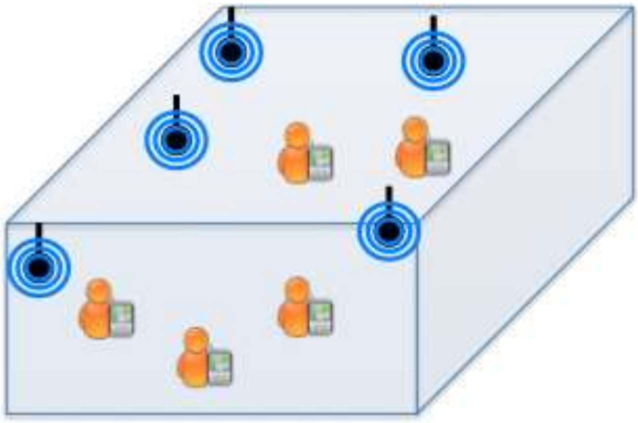

Figure 3.1: An isolated room scenario where small-cells are used to provide indoor connectivity.

Technology mix. Monolithic access points with steerable antennas, limited cooperation among access points

Traffic scenario. A large number of users simultaneously active in peak hours.

Key challenges.

- Mm-wave nano-cells are used to improve the indoor coverage of traditional cellular technology.
- The focus of the mm-wave small-cells is on coverage, therefore small-cell planning and beamforming optimization must be carried out in order to provide coverage to places where devices are expected to stay, using LOS and NLOS transmissions.
- Low interference among small-cells is expected, cooperative transmissions or advanced antenna systems could be used to cover the area reducing the number of deployed small-cells.
- The separated control plane facilitates user mobility within the room, nano-cells can be placed in fixed points with presence of users, while traditional cellular technology can be used as fallback during mobility.
- The scenario has limited mobility, no stringent timing or very smart algorithm should be provided.

3.1.1.2 Large public areas

This scenario consists in an area of multiple open spaces and rooms covered with traditional cellular technologies (LTE, LTE-A) small cells or WiFi, and a large number of mm-wave nano-cells providing full coverage of the space (Figure 3.2). The typical situations described by this scenario are malls, shopping centers, sport facilities, airports, stations, undergrounds, etc.

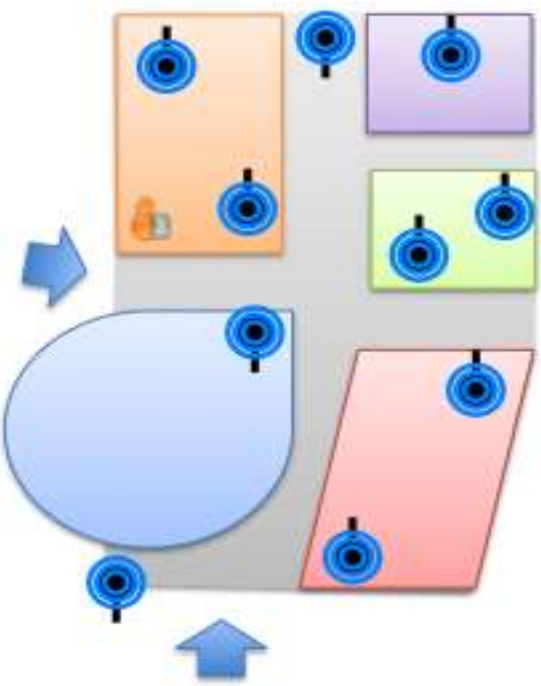

Figure 3.2: A public indoor area where small-cells are used to provide high-capacity to mobile users.

Technology mix: Mix of monolithic access points and RRHs with C-RAN. Different levels of cooperation among access points.

Traffic scenario: A large number of simultaneous active communications in peak hours.

Key challenges.

- Mm-wave small-cells are used to increase the capacity and limit interference strategies. Cooperative small-cell transmissions and coordination with traditional cellular base station could help in covering difficult areas.
- Small-cell placement optimization is required to provide high-capacity to the whole area, cooperative beamforming and interference coordination optimization must be used as well.
- Small-cells are characterized by very high rates and high interference, we have typically LOS transmissions.
- The separated control plane facilitates user mobility within the whole area. Traditional cellular technologies should be seldom used because of limited capacity.

The scenario has stringent mobility requirements but low speed, sophisticated mobility management algorithms must be designed. Due to the small coverage of single nano-cells, their placement should be done according to mobility pattern in order to facilitate handovers.

3.1.2 Outdoor coverage scenarios

Different topologies of outdoor scenarios are identified in this section, according to the area we are required to cover with the mm-wave point of access. Multi-HetNet scenarios dedicated to the combination of different technologies at the PHY/MAC layer and in terms of radio engineering are addressed in the section 3.1.3. Classification may be ranged from a very small area with a single isolated mm-wave hot-spot to a larger scenario with several mm-waves points of access which provide a partial or full coverage of the selected area.

3.1.2.1 Ultra high-rate hot-spots

This scenario consists in a mobile network of traditional LTE/LTE-A base stations which are in charge of providing full coverage through macro/micro cells. Additionally, a number of mm-waves isolated hot-spots are placed within the urban area such as parking lots or far away from the center in emergency refuge on a motorway. Those mm-waves hot-spots cover just tens of meters with a very high transmission rate. The scenario is illustrated by means of Figure 3.3.

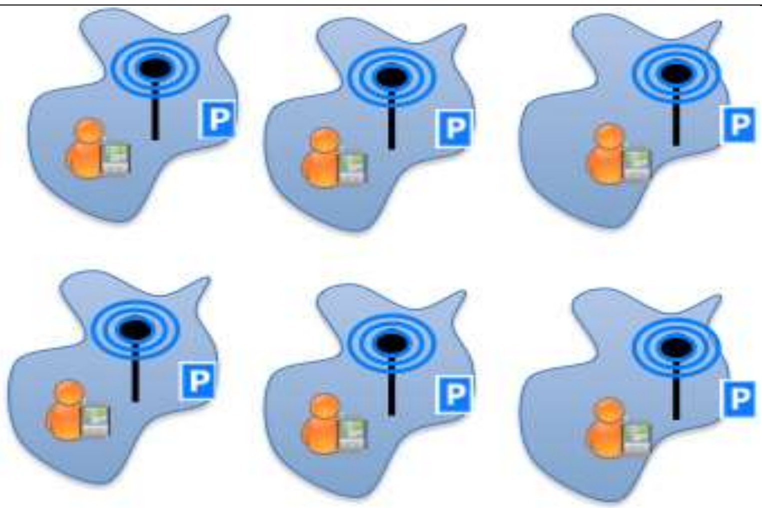

Figure 3.3: A simple scenario with mm-waves hot-spots placed into parking lots.

Technology mix. The scenario includes monolithic mm-wave access points with steerable antennas.

Traffic scenario. Very low traffic. One or very few users can simultaneously require traffic through the isolated mm-waves hot-spot.

Key challenges.

- Mm-wave nano-cells can be used to provide coverage in locations where the coverage of the traditional cellular network is not available by providing a point of presence or they can be used to provide very high capacity in localized spaces within the coverage of the traditional cellular network.
- Since very short distance is required as well as no obstacles are permitted between the hot-spot and mobile users, a smart positioning of the mm-waves hot-spots in optimal places which can be easily reached by the majority of users passing over there. No mobility issues in the Mm-wave hot-spot are expected to occur.
- The separated control plane and the rich context-information can guide mobile user to find these hot-spots and reducing channel acquisition time.

3.1.2.2 High-rate areas

This scenario consists in a new generation mixed mobile network in an urban environment including traditional LTE/LTE-A base stations and a small number of mm-waves small-cells which provide almost full coverage in the area, as depicted inFigure 3.4.. Since each mm-wave small-cell covers small portions of area, a set of mm-waves small-cells is placed in order to cover a broader area. The mm-waves small-cells can perfectly work with the traditional set of LTE/LTE-A base stations without interfering each others, as different carrier frequencies are involved.

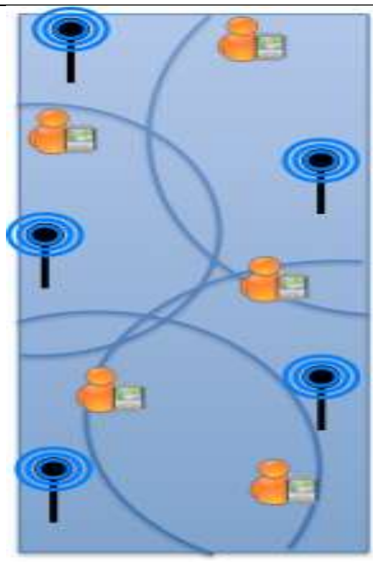

Figure 3.4: An urban scenario where traditional LTE/LTE-A base stations share the same area with mm-waves small-cells in order to improve the coverage at higher rates.

Technology mix: Monolithic mm-wave access points with steerable antennas are required.

Traffic scenario : Typically, we are facing with a dense scenario, in a city center where a pretty large number of users simultaneously can require traffic in peak hours.

Key challenges.

- This scenario requires larger areas to be covered. We expect a lower nano-cell density than in indoor scenarios, therefore a limited number of mm-waves nano-cells may interfere each other. A limited cooperation amongst mm-waves nano-cells is required for mitigating interference, such as basic algorithms for interference alignment.
- LOS and NLOS transmissions are expected to occur, full use of advanced antenna and cooperation techniques to provide high capacity, however large scale antenna systems cannot be used due to the small number of involved nano-cells.
- The mobility management through the separated control plane is another issue to be addressed, however users are expected to have limited mobility.
- The context management decreases data channel acquisition time and can be used for mobility prediction in order to facilitate the handover management.

3.1.2.3 Larger areas

This scenario consists in a new generation mixed mobile network in an urban environment including traditional LTE/LTE-A base stations and a huge number of mm-waves small-cells which provide almost full coverage in the area. The considered area is large. Since each mm-waves small-cell covers small portions of area, a large set of mm-waves small-cells is involved. As shown in Figure 3.5, different mm-waves small-cells work together in order to cover the same area and improve the efficiency. The mm-waves small-cells can perfectly work with the traditional set of LTE/LTE-A base stations without interfering each others, as different carrier frequencies are involved.

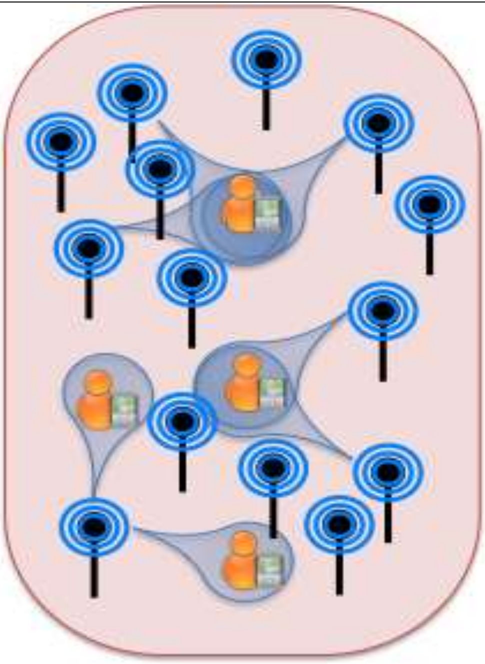

Figure 3.5: A very large urban scenario with traditional LTE/LTE-A base stations sharing the same area with mm-waves small-cells to supply localized high rate coverage

Technology mix. Mix of monolithic access points and RRHs with C-RAN.

Traffic scenario. Typically for the current scenario we are facing with a dense scenario in a large area where a pretty large number of users simultaneously can require traffic in peak hours.

Key challenges.

- The scenario is characterized by many and densely deployed small-cells that interfere each other. Therefore, the highest cooperation amongst mm-waves nano-cells is required, such as CoMP techniques by performing a coordinated scheduling. Moreover, in some case different small-cells may provide the same traffic to the same user using large-scale antenna systems. In that case, Joint Transmission (CoMP-JT) techniques are required in order to exploiting the cooperation between different small-cells.
- Small-cell placement optimization is required to provide high-capacity to the whole area, cooperative beamforming and interference coordination optimization must be used as well.
- The mobility management through the separated control plane is another issue to be addressed; users are expected to have very high and differentiated mobility. The separated control plane together with native mm-wave techniques should be used to design a sophisticated mobility management.
- The context management decreases data channel acquisition time and can be used for mobility prediction in order to facilitate the handover management.
- The traditional definition of static cell may be no longer adequate, the dynamic cell structuring can be implemented to match the characteristics of the scenario. Virtual cells can be created (and released) on-demand to serve specific users by means of the cooperation among different small-cells.

3.1.3 Multiple RAT HETNET scenarios

Multi-RAT HetNet architectures refer to the combination of different technologies in by considering PHY layer aspects and cross layer mechanisms related to MTLA and MIM processing respectively. The major approach to increase capacity to 1000 time is to combine licensed and unlicensed band interfaces and extend indoor and Short Range Distance (SRD) systems to outdoor Hot Spot extensions and mm-wave band exploitation.

3.1.3.1 PHY layer extensions and mm-wave bands

The Wi-Fi extension to Hot Spot deployment is feasible following first link budget assessments involving transmitter and receiver antenna gain adaptation. Typically, following studies led in the IEEE802.15.3c Study Group, equivalent Omni-directional antennas will be built by combining directive antenna and fast spatial switching for multi-user connections (Figure 3.6).

Antenna gain adaptation will be evaluated upon indoor and outdoor environments associated with use cases detailed in the section 3.4.

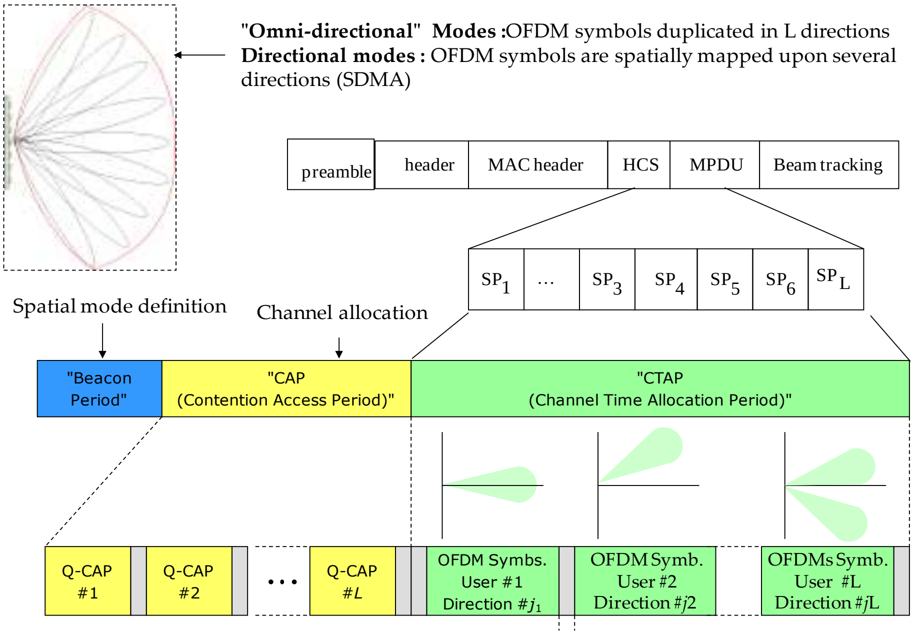

Figure 3.6: Antenna gain adaptation and fast antenna switching

SRD and UWB technologies radio coverage extensions would require a spectrum transposition in mm-wave bands and higher power levels in accordance with power and frequency regulations. This technical point addressed in indoor scenarios [SUM,09], will be investigated focused on mm-wave bands for both indoor and outdoor deployment scenarios using link budget analysis and system parameter dimensioning

New waveforms derived on the one side from Multi-Band OFDM UWB standards (ie ECMA-368 [ECMA,08] and ECMA-387) and on the other side on spatial focusing techniques as the Time Reversal (TR)[BSU,13][BS,13] covering mm-wave transmissions will be also studied to improve radio coverage, limit interference and increase the global multi-user capacity of such systems. Indoor and outdoor hot spot environments will be considered.

3.1.3.2 Multi-Technology Link Adaptation Techniques and implementation

Usual link adaptation techniques considered in the 3GPP are based on a spectrum efficiency optimization and a single air interface. Pilot signals carry out RSSI measurements, quantize power levels upon 16 levels and forward 4-bit CQI to the e-Node B upon reverse link using CQICH channel. The Base Station selects the transmission mode under proprietary algorithm.

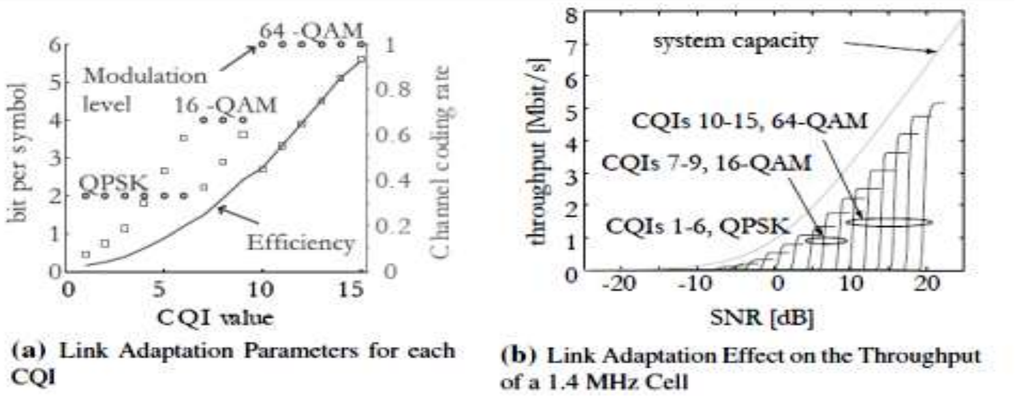

Figure 3.7 : CQI metric and link adaptation procedure in the 3GPP standards [Pel13]

In a multi-technology access scenario, complementary link adaptation metrics have to be designed to encounter independent interfaces exhibiting different class of power sensitivity levels and throughputs. Dedicated metrics will be designed considering in particular mm-wave link budget parameters related to outdoor and indoor deployments (see section 3.3.1), in order to define the best trade-off between the required transmit power level to supply desired QoS and the targeted radio coverage. Energy Efficiency and transmit power minimization will be integrated in the metric definition criterion.

The implementation of such new CQI metrics using existing protocols and CQI mechanisms will be regarded to ensure compatible cross layer mechanisms with existing protocols. For that purpose, CQI and MIM mechanisms derived from the 3GPP processing and the ICT-FP7 OMEGA project [OMEG2+11] which utilizes a L2.5 layer to emulate different interfaces will be analyzed to switch between independent interfaces. The Fast Session Transfer (FST) [FST,10] algorithm allowing a fast switching between Wi-Fi technologies, ie IEEE802.11ac and IEEE802.11 ad standards operating respectively at @5GHz and @60 GHz, will be examined and potentially extended to other technologies. The ANDSF [3GPP_AND,13] protocol allowing Wi-Fi system discovery in 3GPP active cells will be investigated to perform Wi-Fi/LTE-A convergence.

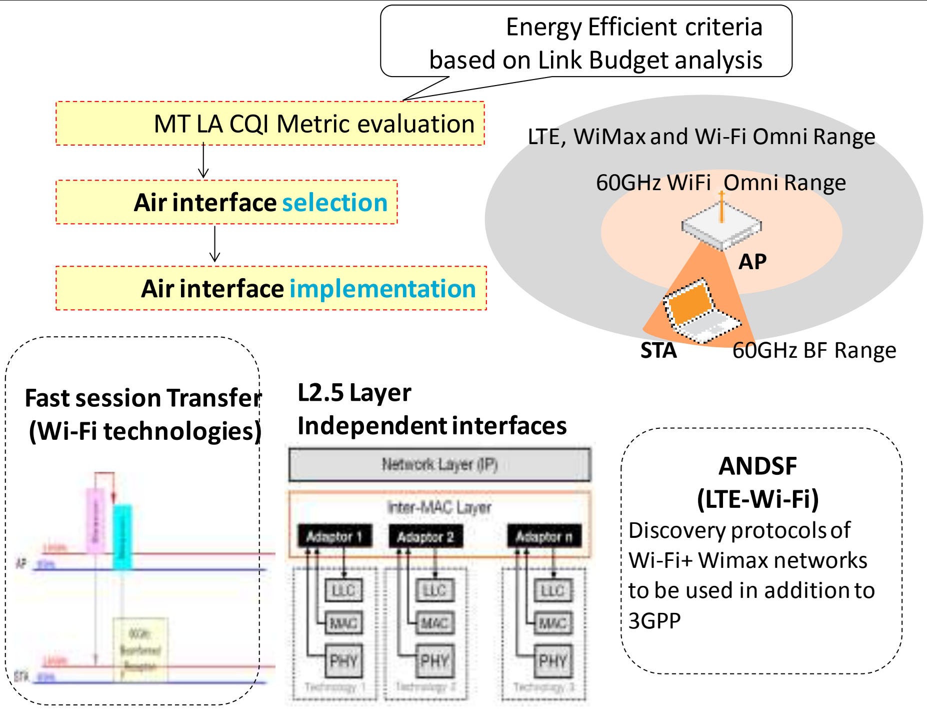

Figure 3.8: MTLA techniques for multi-Technology HeTNeT deployments

3.1.3.3 Multi-RAT deployment architectures

The third aspect of Multi-HetNet scenario is focused on the densification network optimization in indoor and outdoor environments. Radio engineering tool will be exploited to select the most appropriate interface depending on LOS/NLOS criteria, environment topologies and to optimize Inter-Cell Distance (ICD) in urban areas by considering MTLA metrics mapped into a radio engineering tool. A dedicated algorithm will supplies, following metrics variations, the candidate interface in each local zone. Furthermore, the radio engineering tool extensions allows positioning access points and base stations in order to ensure radio coverage with a transmit power minimization.

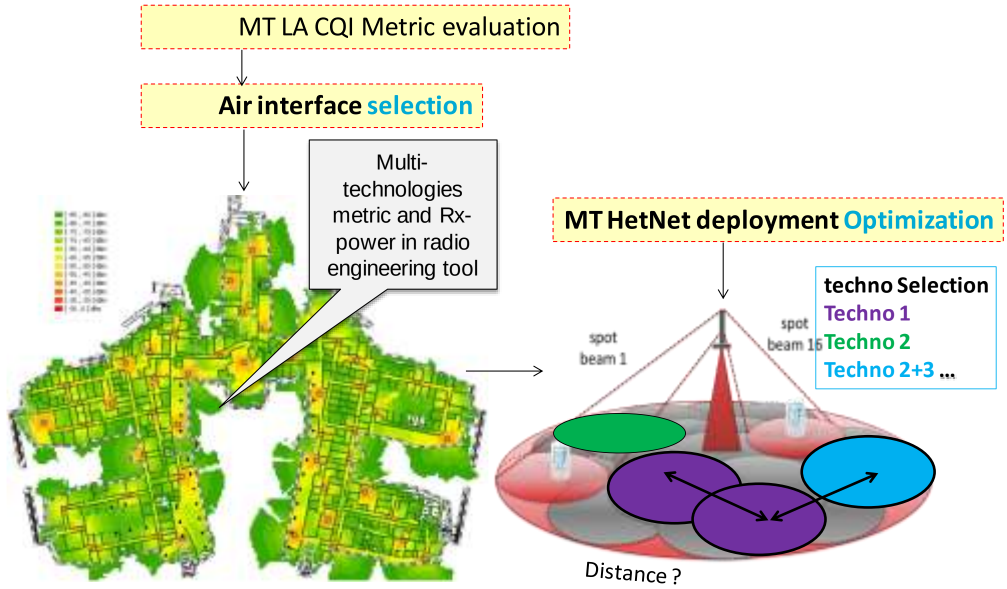

Figure 3.9 : Multi-Technology interface selection and Multi-Technology HetNet architectures

Indoor environment will be focused on Wi-Fi technology combination and UWB transmissions (see 3.4.3) considering RF multi-Band PHY layer extensions and MIM using FST and an additional L2.5 layer.

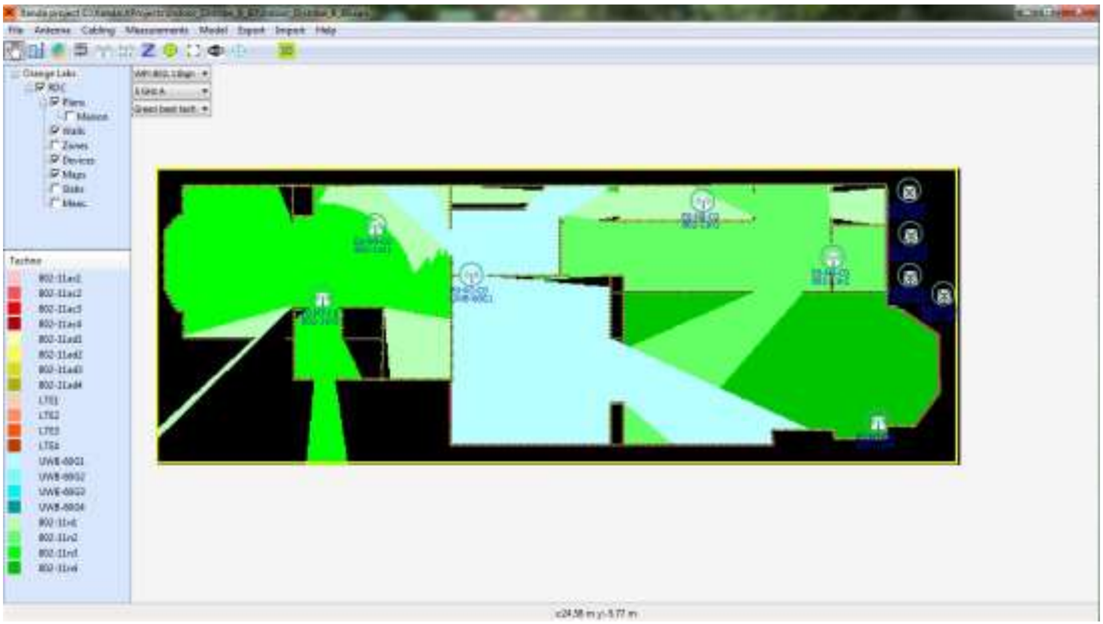

Figure 3.10 : Example of interface selection vizualisation in the home networking use case

Outdoor and hot spot environments will encompass Wi-Fi technologies combined with LTE-A and cellular technologies.

3.2 Backhauling and fronthauling scenarios

Backhaul and Fronthaul connections refer to intermediate links between the core network and the small sub-networks attached to a macro-cell usually a Base Band Unit (BBU) and the connection between a BBU a Radio Remote Unit (RRU) respectively. (see section 2.1.3).

A typical macro and small cell deployment challenge is the provisioning of cost efficient fixed line type connectivity between base band units (BBU) and remote radio units (RRU) if fiber is either not deployed or not available at certain locations, setting an urging need for wireless connections supporting carrier grade connectivity between BBU and RRU in the C-RAN architecture. More specifically, reliability, latency, synchronization jitter, load adaptive wireless fronthaul capacity, daisy chaining and quasi zero installation and maintenance effort are a few out of many key requirements for such wireless links. In the context of this project we will focus on mm-wave technology to fulfill these C-RAN and HetNet specific requirements. The mm-wave wireless front- and backhaul links are required to support point-to-point (P2P) and point-to-multipoint (P2MP) topologies and to be set-up and operated in a self-organized and self-optimized manner. Furthermore, the density of such mm-wave front- and backhaul links might be very high at certain locations requiring advanced link coordination schemes to satisfy carrier grade QoS.

Link optimization using directive beams is of high importance, similar like for the access link but more in the sense of optimization of static or quasi-static links. Suitable concepts are discussed in more detail in the following paragraphs.

3.2.1 P2P & PMP scenarios

3.2.1.1 Multi-Technology backhauling Fronthauling deployment

P2P and PMP backhaul scenarios refer to the wireless connections between the macro-cell and the phantom cells. As detailed in the architecture section (2.1.2), the work will be focused on the appropriate technology selection to transport data rates to be distributed in the small cell between users and guarantee radio coverage between the base station and the small cell by considering different wireless segments used in classical backhaul architectures (microwave nomenclature) and Multi-Hop Relay transmissions.

Another description of backhaul usually adopted for microwaves makes reference to middle and last mile connections as illustrated below (Figure 3.11).

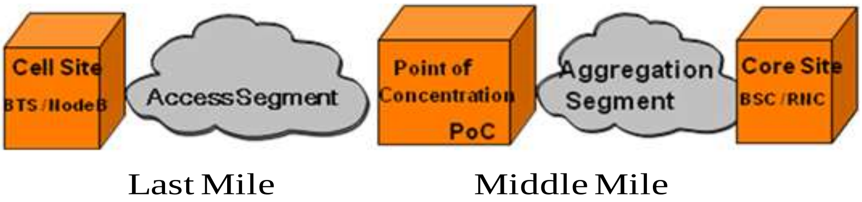

Figure 3.11: Microwave based backhaul architecture and nomenclature

Several technologies will be considered to perform backhaul/fronthaul transmissions: microwave and IEEE802.22 technologies for rural environments and metropolitan areas with limited throughput and low cost deployment and Wi-Fi technologies, LTE-A and IEEE802.16e technologies to cover urban areas with higher throughput up to several Gbps on the bakhaul/front haul link.

A sub scenario is depicted below where Wi-Fi technologies and LTE self backhauling are exploited to perform backhaul and distribute throughput between users in the small cell.

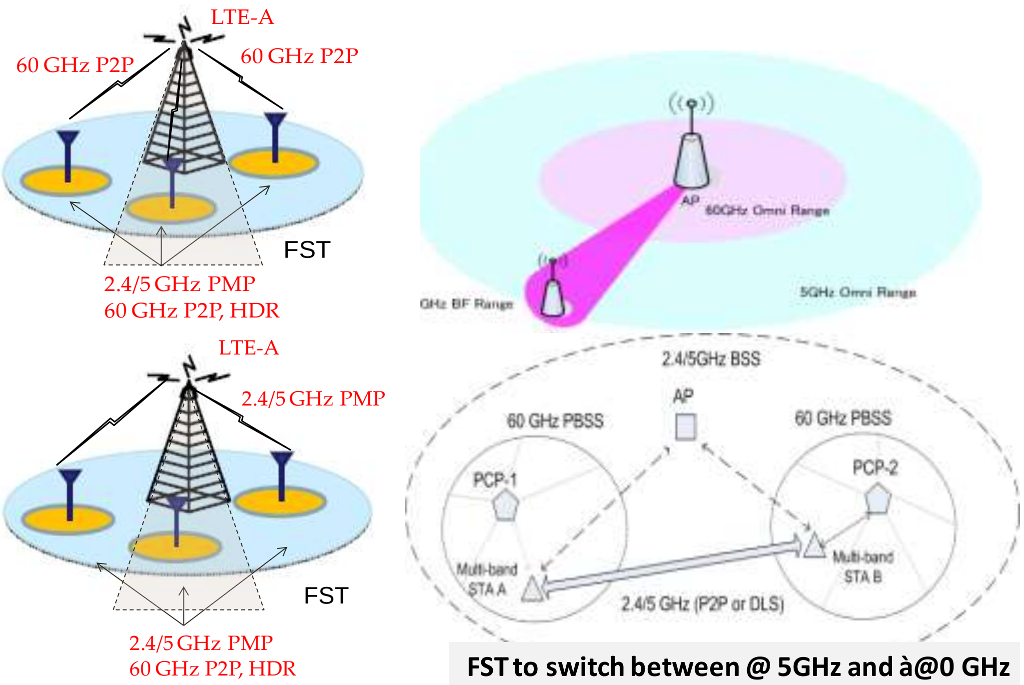

Figure 3.12: Front Haul/backhaul deployment using Wi-Fi technologies and FST mechanisms

The air interface selection on each segment will resort from link adaptation processing detailed in the access scenario section (3.1.3.2) combined with the throughput requirement within the small cell. The interface switching will use FST mechanisms adopted in the IEEE802.11 ad standard [FST,10][IEEE802.11ad,13].

COM'P concept arisen from the LTE-A standard may be investigated to implement Mobile Mobile Relay in dense urban areas [3GPP_MR,13]. COMP consists of sending and receiving signals from different sectors and cells to a given UE. The coordination of signals between different cells allows interference reduction, cell-edge capacity increase and inter-cell seamless radio coverage. COMP adaptation and implementation is investigated here as an advanced backhauling solution which stays a long term solution to be deployed in dense and urban areas. COMP concepts are detailed in many papers [LTE_1][TNT,11]. Multi-Hop transmissions will be covered in this sub-scenario focused on joint processing to limit interference and RRM in connection with WP4 activities and RRM scenarios.

3.2.1.2 Self-backhauling

PMP scenarios will cover self-backhauling schemes as considered in the 3GPP standard with a resource sharing between backhaul and access links (fronthaul) and mitigation of self-interference by means of frequency separation of backhaul and access link (out-band) and time domain separation by coordinated Tx and Rx phases (in-band)[Hoy,11] (Figure 3.13). Self-backhauling will be adapted to mm-wave and wireless segments for middle and last mile connections.

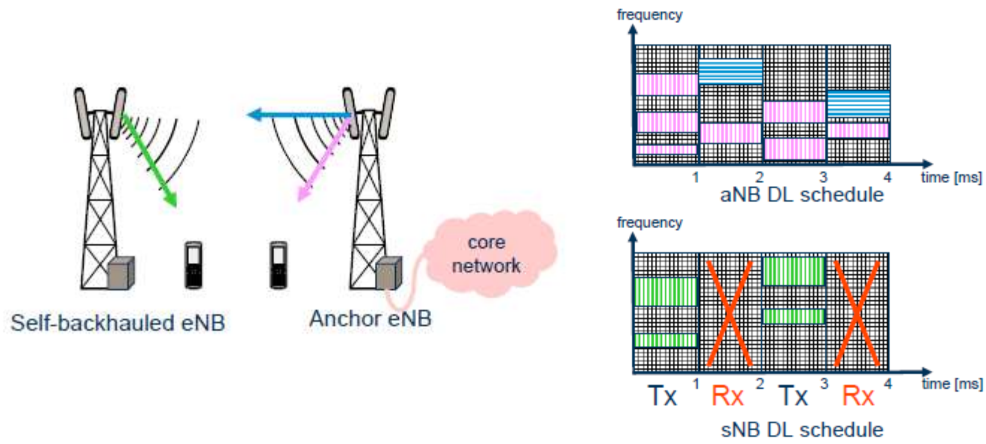

Figure 3.13: Self backhauling based on backhauling and access separation in the time and frequency domains extracted from [Hoy,11]

.The second more generic approach is the general separation of transmission link between the RRH and the BBUs using adequate transmission links which limit transmit power on each segment and between users.

3.2.1.3 Adaptive and active antenna combined with mobility and locations

MMR stations focusing on communications with mobile terminals may be considered for backhauling in dense urban areas. This technical requirement involves spatial tracking between RSs and mobile terminals. Handovers and terminal locations will be encountered to perform communications. Wireless backhauling combined with both beamforming/spatial focusing techniques and Radio Ressource

Management (RRM) will be analyzed and implemented in MiWEBA architectures. Car-to-Car communications will be tackled as a sub-use case where the mm-wave relevance using fast tracking beamforming will be examined.

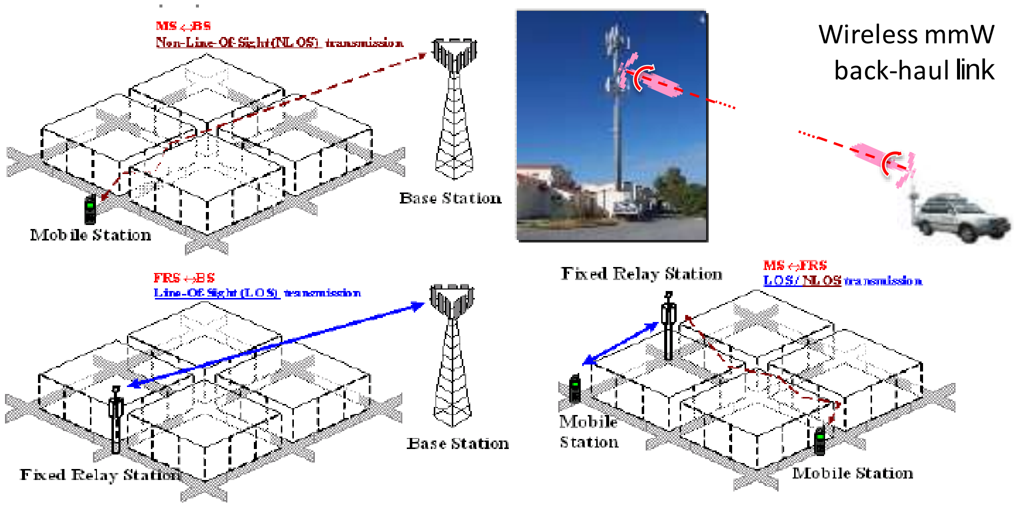

Figure 3.14: MMR (extracted from [MNP,06] and vehicular MIMO architectures in urban areas

3.2.2 Relay-node based topologies

Relay node topologies will be investigated by considering:

- MMR topologies as envisioned in the IEEE802.16j where base stations and Relay Stations manage communications between users
- COM'P algorithm adapted to multi-Hop Relay Node deployment
- Multi-layer relay node architectures will be investigated focused on a comparison between layer-1, layer-2 and layer-3 technologies.

These architectures may be either deployed in urban and metropolitan areas.

3.2.2.1 MMR topologies and COM'P MIMO processing

Mobile Multi-hop Relay (MMR) station system may be adapted to Multi-Technology back-haul and front-haul solutions using Relay Stations (RS) to perform multi-hop backhaul transmissions. Relay features developed within IEEE802.16 under 802.16j extension [IEEE802.16j,09] for a single technology will be examined to extend the concept to multi-technology where RS are connected together using multi-hop transmissions and proper technology on each link. The major problem is to identify technologies that ensure data rates compatibility between middle transmission and multi-user Last Mile transmission.

In the IEEE802.16j standard, two different modes denoted centralized and distributed scheduling are specified for controlling the allocation of bandwidths :

- In centralized scheduling mode, the bandwidth allocation for an RS's subordinate stations is determined at the MR-BS.
- In distributed scheduling mode, the bandwidth allocation of an RS's subordinate stations is determined by the RS, in cooperation with the MR-BS.

Two different types of RS are defined, namely transparent and non-transparent. A non-transparent RS can operate in both centralized and distributed scheduling mode, while a transparent RS can only operate in centralized scheduling mode.

These protocols will be examined to define MT wireless backhaul and fronthaul architectures integrating mm-wave components. COM'P MIMO processing will be adapted to mm-wave deployments

3.2.2.2 Multi-Layer Relay Node architectures

Multi-layer Relay node architectures are one of key components of MMR communications focused on different signal processing level to perform multi-Hop communications.

Layer 1, Layer 2 and Layer 3 Relay processing will be compared and adapted to Wi-Fi and mm-wave transmissions by considering the impact on power consumption and complexity of these different topologies. Latency will be regarded for these architectures and combined with RRM optimization.

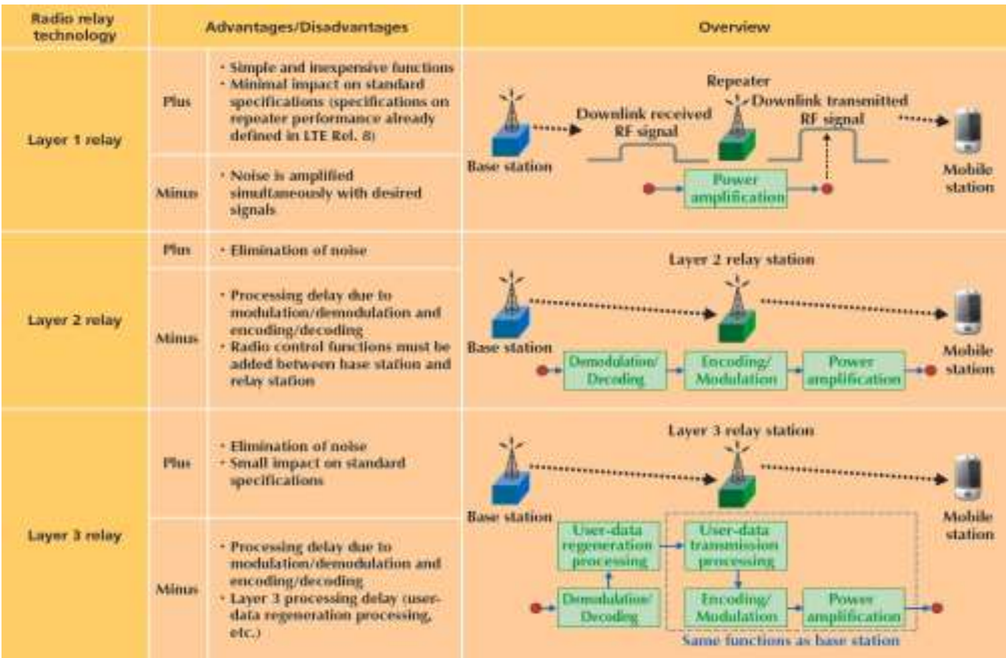

Figure 3.15: Multi-layer Relay Node schemes, figure extracted from [IT,12]

3.2.3 Multi-Technology Backhaul decision scenarios

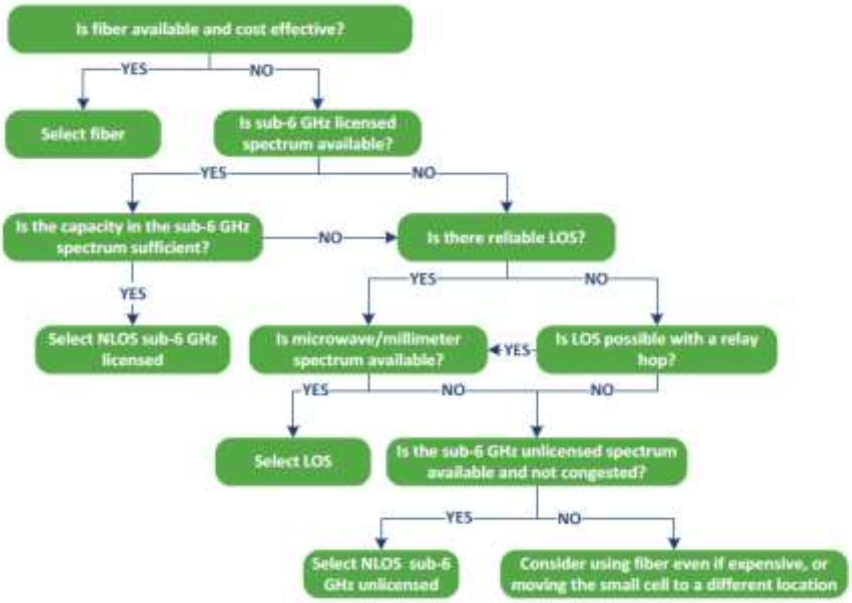

Figure 3.16: Backhaul decision tree [SFC 2013].

Different Multi-Technology backhaul decisions will be compared together in terms of complexity, scalability and deployment costs. MTLA algorithms developped in the access scenarios (see section 3.1.3.23.1.3.3) will be adapted to backhaul and front haul scenarios.

3.3 Models for network scenarios

3.3.1 Requirements for channel models

The channel models that will be developed in WP5 of MiWEBA are an important building block for the other work packages. The models will focus on the millimeter-wave range around 60 GHz and should be well adapted to the scenarios described in this document. Concerning the channel properties we assume that we can distinguish between indoor and outdoor propagation. In indoor environments there usually exists a large number of reflecting objects that guarantee a multipath environment. This is not evident for outdoor scenarios. A large amount of work has been done in the past on millimeter wave indoor propagation in connection with the recent millimeter-wave standardization activities in e.g. IEEE802.15.3c [PSM,06][MEP,09] and IEEE802.11ad. For outdoor environments there has been less activity as the applications up to date mostly focus on fixed point-to-point links. These environments are therefore under focus for the MiWEBA research activities.

The requirements for the models however vary among the work packages. For the purpose of system evaluation at network level a system level simulator framework will be set up in WP4. For the reason of speed and reproducibility the underlying link level and channel model can be simplified to a reduced parameter set. The choice of adequate parameters will be based on initial knowledge of the channel properties and will be done in joint cooperation between WP4 and WP5.

On the other hand the development of highly-directional steerable antennas, beam steering techniques and optimized PHY/MAC layer requires a thorough knowledge of the channel properties. For this purpose parameters such as the distribution of angles of arrival, delay spread, blocking margins (caused e.g. by passing pedestrians), foliage attenuation, path loss, etc. will be required. The influence of the surrounding environments has to be taken into account for this purpose. For the millimeter-wave channels we expect a stronger dependency on the actual location than at the legacy mobile radio network frequency bands. It is therefore expected necessary to validate this assumption and generate models that are based on statistical properties of a large number of different environments.

3.3.2 Requirements for traffic models

Since the performance of a wireless network is strongly influenced by the distribution of the traffic it is serving, the definition of accurate traffic models in of great importance in order to evaluate the potential benefit of the new architecture proposed in MiWEBA project. In this section we draft the main characteristics of traffic models which will be refined and integrated during the project work on the base of the most important issues coming from architectural choices.

We have basically two ways to describe the user traffic:

1) Total traffic volume and its breakdown, the total value of traffic in a given playground, its breakdown into regions, and service types;

2) Traffic variation in time and space;
Therefore, the traffic model we develop shall capture the main features in these directions correspondingly. In particular, as for the second direction, since we are mainly interest in serving the highest peak of traffic during the day/week, we can focus only on traffic space variations. Temporal traffic variations can be summarized with simple daily profiles defining traffic levels at different periods of the day as a function of the average/peak daily rate. They are mainly related to the energy consumption of the system and their applicability depends on their impact on the energy efficiency, which will be investigated in the future work.

Moreover, we also need to be aware of the facts that:

• The traffic volume would be greatly related with factors such as population density, the penetration rate, and human activities.

• A complete network is way too complicated to be simulated.

• Breakdown allows identifying the big potentials (on which critical scenarios should research and development focuses).

• Different solutions will apply for different scenarios, so we need to know which scenarios are typical in a network.

As a result, in our modeling, we would prefer to divide the whole playground into different types of areas according to the typical features such as population density, and then characterize the traffic model for each of the area type. Since mm-wave communications are expected to be effective at high-population densities, we consider only urban scenarios distinguishing between average urban densities and

very high densities in the city center. Along with average values we may consider standard deviations as well.

The second important issue is related to the space traffic variation. A model to describe traffic concentration points (hot zones) is needed. Each of zone is described by a central point and the size of its surrounding area. The model must describe the density of hot zone centers, the shape and the size of the surrounding areas, and the different user densities inside and outside the hot zone.

On top of area and population aspects, the traffic must be characterized by the service profile which describes the user-generated data traffic. Therefore, a potential service mix indicating the traffic breakdown among different types of services and their respective traffic parameters must be included in the model.

Note that, since the population density and penetration rate also have impact on the way of how network is deployed, the deployment and traffic models are inevitably related with each other in practice. However, in order to characterize the features for each of them, in this document, the traffic model is developed without any relation on the deployment model so that different deployment strategies can be independently analyzed under the same traffic scenarios. In other words, the deployment model and the traffic model are decoupled and considered in an orthogonal manner.

3.3.3 Requirements for RRM

The role of RRM is to control radio resources of UEs and small BSs based on mobility and traffic demand of UEs as well as available supply capacity of all BSs. The function of RRM is normally implemented in BBUs of C-RAN since it is easy to collect required information and control radio resources of UEs and small BSs within the coverage of macro BS as described in Fig. 3.6. The objective function of RRM is basically to maximize average system rate under the constraint of QoS (data rate, delay, etc.) in each application of all users.

Parameters of RRM for UEs include

- Wake up (activation)
- Cell & technology selection
- Handover among macro BS and small BSs.

On the other hand, parameters of RRM for small BSs include

- BS dormancy (deactivation)
- Antenna beam control (for dynamic cell structuring)
- Channel selection
- Transmit power control.

It is required to develop efficient optimization algorithm in C-RAN by taking into account the scale of time variation in each parameter.

If the number of RRUs in C-RAN is too large, it is better to introduce hierarchical (multi-level) HetNet where RRM is performed not only at centralized BBU but also at distributed BBUs in the HetNet. In that case, distributed RRM can reduce latency of

resource control by limiting the number of RRUs in the distributed BBU, while the global optimality of the system should also be achieved. Lastly, the RRM for small BSs located at the edge of cluster, where inter-cluster interference may occur, is remaining item for study. In such area, the RRU should be shared by multiple BBUs surrounded to the RRU to perform inter-cluster (C-RAN) interference cancellations.

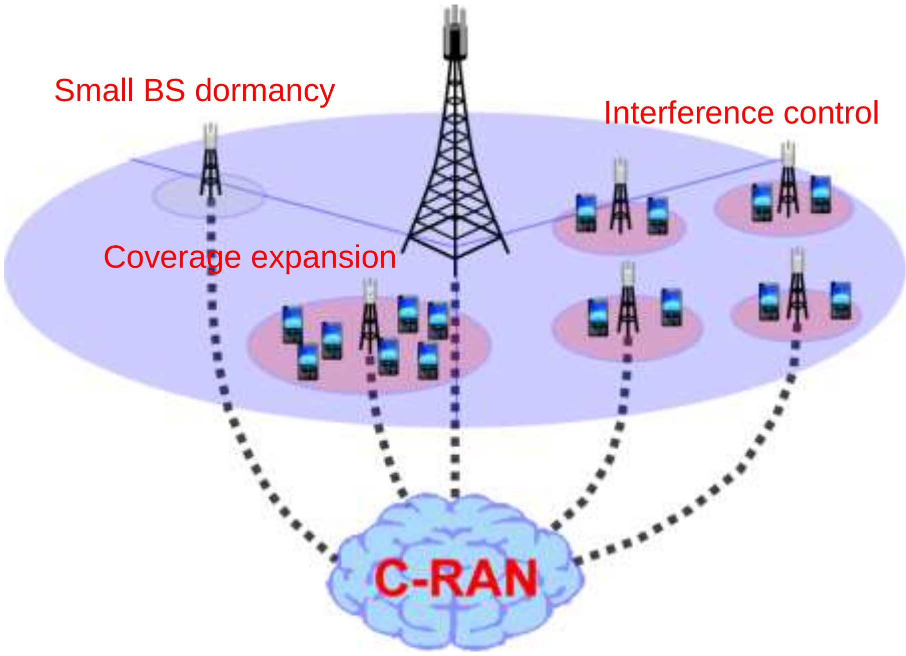

Figure 3.17: C-RAN based radio resource management for HetNet.

3.4 Use cases

In the project, mm-metric technologies will be mainly used in dense urban scenarios to provide high data rate services through hotspots and related backhaul. However, mm-metric transmissions can also provide wide area coverage to mobile users by exploiting tracking capabilities and adaptive beamforming.

After discussion within MiWEBA partners, five main scenarios have been defined in WP1.

- Indoor Hotspot focus:

  S1: **Dense Hotspot in Shopping Mall**

  S2: **Dense Hotspot in an Enterprise**

  S3: **Dense Hotspot in Home Environment**

- Indoor/Outdoor Hotspot focus:

  S4: Dense Hotspot in a Square

  S5: Dense Hot Spot in Urban areas

- Outdoor Non-Hotspot focus:

  S5: Mobility in the city

  S6 : Bakhauling and Fronthauling in both dense Urban and Metropolitan areas

A more detailed description for each scenario can be found in the following subsections.

3.4.1 Dense Hotspot in a Shopping Mall

3.4.1.1 Generic Description

Ad-hoc deployment of small/nano cells is an efficient solution to cope with the ever increasing demand of high data rate traffic, which is mainly originated indoors. Shopping mall may be located outside the city centre i.e., in rural and suburban areas where the capacity of the macro cell based network is reduced due to propagation and penetration losses. Also, bringing optical fiber in these locations may be unaffordable and wireless backhaul solutions may be preferred to efficiently enable high data rate services in the mall.

Inside the building, small/nano cell deployment avoids outdoor to indoor propagation losses and benefits of the favourable radio environment characteristics to offer an enhanced wireless service. Technologies based on 60 GHz transmissions allow larger bandwidth at the cost of an increased requirement in terms of number of deployed cells. Furthermore, in the shopping mall, small/nano cells can be deployed either by the shopping mall owner in a planned fashion or by each shop to provide additional services (such as adverting, internet connection) to the customers in an unplanned manner.

Our objective in this use case is to evaluate the performance of a system that uses dense deployment of heterogeneous cells based on different multi-RAT technologies to offer high data rates in an indoor scenario, with a variety of services and constraints.

Depending on the backhaul characteristics (in terms of latency and capacity) C-RAN may be envisaged as a potential enabler to enable network coordination and improved performance.

However, when only wireless backhaul is available between the central entity and the cells located into the shopping centre, only partial coordination is feasible and self-organizing mechanisms are required.

3.4.1.2 Applications and services

Applications and services are related to multimedia services for end users and professional applications close to high data rate loading data files.

Waiting for the lunch at one of the mall cafeteria, users usually use their smartphone/tablet for web browsing or video streaming leading to a high density of traffic in a very small area. Moreover, the shop can also use interactive messages, which contain videos or images, to promote their products or inform customers about special offers.

3.4.1.3 Technical Challenges and Objectives

The key technical challenges in such scenario are the following:

- **HetNet coexistence**: Small/nano cells deployed in a dense ad hoc fashion will require self-organizing interference management mechanisms to enable reliable wireless services.
- **Multi-RAT coexistence**: Different radio technologies may be used by shops and restaurants: intelligent load balancing and offloading techniques will be required to improve the overall wireless network capacity.

- **Backhaul deployment:** Fiber and wireless based backhaul could be deployed to bring data from the core network to the mall building as well as to transport data inside the mall towards the radiating elements (fronthaul).

The main goals in this scenario are:

- **High QoE:** Advertising services target both nomadic and static users and may have different data rate requirements but generally require very low latency; moreover, high data rate services can be offered to static users located in cafeterias and restaurants.
- **Area Spectral Efficiency:** Locally very high data rate may be required in the shopping center, hence the system has to be able to offer high area spectral efficiency to cope with this requirement
- **Energy Efficiency**: Depending on the hour of the day as well as on the number of customers present in the mall, the number of required active small/nano cells should vary. Energy-aware activation and deactivation mechanisms jointly with load balancing may notably improve the system efficiency while maintain locally QoS constraints.

3.4.1.4 Summary

The table below resumes the main characteristics of this scenario in terms of deployment, architecture, traffic, and transmission parameters.

Deployment scenario	Type of deployment	Hotspot
	Outdoor / Indoor	Indoor
	Small cell/user density	High cell and user densities
	User mobility considered	Nomadic/Static
	Planned or unplanned deployments	Mainly unplanned
	Traffic	Video Streaming, web browsing, VoIP, etc
HetNet	Macro cell considered	
	Small cells considered	yes
	HetNet interaction envisaged	Yes
Multi-RAT	WiFi considered	yes
	Multi-RAT interaction envisaged	yes
Nano cell	C-RAN	Yes
	C/U Plane split	
	Direct mm-waves cells interactions considered through X2 like interface	

RAN	Frequency	
	Bandwidth	
Backhauling	Frequency	Wi-Fi and LTE-A bands
	Bandwidth	Up to 2160 MHz
Fronthauling	Frequency	Wi-Fi and LTE-A bands
	Bandwidth	Up to 2160 MHz (Wi-Fi)

3.4.2 Dense Hotspot in an Enterprise

3.4.2.1 Generic Description

Recent surveys show that over 60 percent of mobile subscribers complain about poor service in the workplace. In fact, proving ubiquitous coverage and high capacity in enterprise space is a big challenge for mobile service providers. Since enterprises buildings are characterized by different characteristics in terms of location, age, size, shape, number of rooms, etc finding a unique solution to offer high data rate mobile services has not been feasible for cost and scalability reasons. In addition to these classic issues, today wireless solution for enterprises have to deal with the increasing capacity demands due to laptop, smartphones, and tablets. Moreover, seamless enterprise mobility is a strong requirement for enabling to conduct the business where most appropriated (i.e., from offices to meeting rooms and laboratories). Accordingly, mm-waves technologies can provide high data rate to static users in their offices while other systems such as macro cell based cellular network and small cells may provide reliable connectivity to mobile users.

3.4.2.2 Applications and services

A user may profit of the high data rate provided by a nearby nano cell to perform video conference that enables to discuss in real time the status of a collaborative project with other partners. Moreover, small cells with larger coverage with respect to the 60 GHz base stations enable a user that moves from his office to a laboratory to maintain the connectivity to the local intranet as well to internet and for instance exchange mails with his colleagues. C-RAN may be very useful in this scenario to enable seamless handover between different radio access technologies.

Our goal here is to assess the performance of a system that provides high data rate services through dense deployment mm-wave nano cells to indoor static users as well as medium low data rate services through multi-RAT technologies to indoor nomadic users.

3.4.2.3 Technical Challenges

The key technical challenges in such scenario are the following:

- **Multi-RAT coexistence**: Different radio technologies may be used inside the enterprise to enable wireless services inside the offices and for mobile users in the corridors: henceforth, efficient handover mechanisms are required.

- **Backhaul deployment:** Fiber and wireless based backhaul could be deployed to bring data from the core network to the mall building as well as to transport data inside the mall towards the small cells.

The main goals in this scenario are:

- **Area Spectral Efficiency:** very high data rate may be required locally at certain moment in the enterprise for instance to download new software, hence the system has to be able to offer high area spectral efficiency to deal with this objective.
- **Energy Efficiency:** Traffic daily profile in enterprise will likely shows a regular pattern during the day with low load periods around midday (because of lunch) and when workers start to leave the enterprise and typically no loads during nights; this profile holds on a weekly time scale, however, during weekends the enterprise may be closed. Energy-aware activation and deactivation mechanisms jointly with load balancing may notably improve the system efficiency while maintain locally QoS constraints.
- **Cost Efficiency**: Cost effective solutions should be preferred in order to limit capital expenditure in the enterprise, reuse of the pre-existing infrastructure may be highly preferred with respect to a complete update of the network.
- **High QoE:** Very high data rate services such as FTTP and video streaming target static users and may have different data rate requirements in terms of capacity and latency; however, nomadic user will require mainly medium data rate services such as Voice over IP and access to the local intranet.

3.4.2.4 Conclusion

Deployment scenario	Type of deployment	Hotspot
	Outdoor / Indoor	Indoor
	Small cell/user density	High cell and user densities
	User mobility considered	Nomadic/Static
	Planned or unplanned deployments	Mainly planned
	Traffic	Video Streaming, web browsing, VoIP, etc
HetNet	Macro cell considered	
	Small cells considered	yes
	HetNet interaction envisaged	yes
Multi-RAT	WiFi considered	yes
	Multi-RAT interaction envisaged	yes
Nano cell	C-RAN	Yes

	C/U Plane split	yes
	Direct mm-waves cells interactions considered through X2 like interface	yes
RAN	Frequency	
	Bandwidth	
Backhauling	Frequency	
	Bandwidth	
Fronthauling	Frequency	
	Bandwidth	

3.4.3 Dense Hotspot in Home and indoor environments

3.4.3.1 Generic Description

Nowadays, WiFi is the most common way to access to wireless applications/services at home. However, Wi-Fi uses unlicensed bandwidth and it is difficult to predict the perceived interference and traffic load due to the ad-nature of WiFi access points (AP) [Qualcomm, 11]. Seamless mobility is also constrained in many Wi-Fi deployments as in this system end terminals search for a better AP only when the strength of the signal received from their serving AP becomes too weak. Therefore, Wi-Fi is better suited for best effort applications that do not require guaranteed QoS. Moreover, current solutions do not provide seamless handover between cellular networks and WiFi as 3GPP standard considers Wi-Fi as an unreliable technology [Qualcomm, 11]. Here, we want to investigate solutions to provide high data rate capacity in the home environment through an evolutionary path of WiFi.

In MiWEBA, users at home may experience guaranteed QoS and enhanced capacity at the cost of an increased number of APs, since with the mm-waves APs will not be able to pursuit mobile users from a room to another. However, inside each apartment nano cells will benefit of the favourable radio environment characteristics that avoid interference amongst neighbouring apartments to offer an enhanced wireless service. Therefore, in locations where dense deployment of femto cells is not a viable solution due to the strong inter-cell interference, mm-waves technology can be used as an alternative to provide high quality of experience in indoor.

3.4.3.2 Applications and services

Typical use cases focused on unlicensed bands technologies deployed in inddor environments are depicted below where UWB technologies transposed at 60 GHz are combined with Wi-Fi technologies encompassing IEEE802.11 {ac/ad} standards and IEEE802.15.3c operating in the 2.4/5 GHz and 60 GHz bands. UWB technologies operate in the {3.1-10.6} GHz and in the {57-66} GHz RF bands. Mm-wave bands allow higher transmit power levels and higher radio coverage ranges.

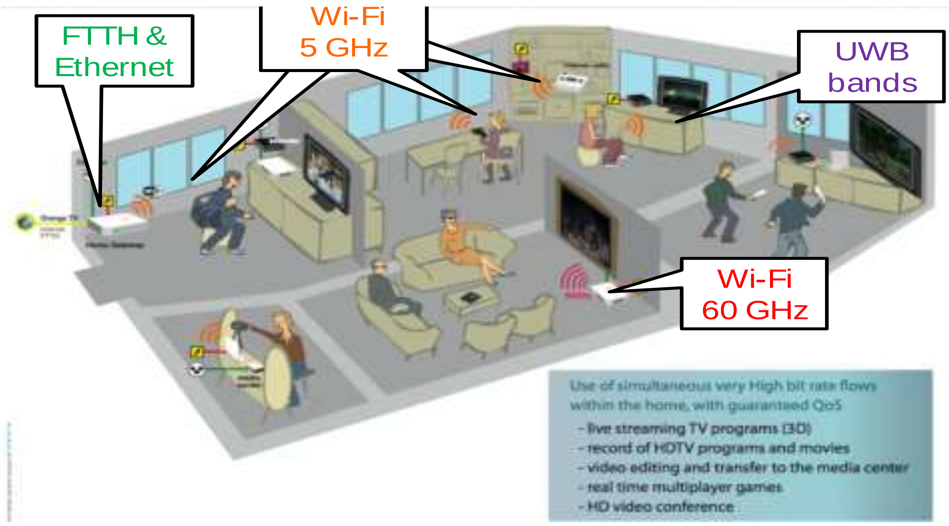

Figure 3.18: Wi-Fi based and UWB transmission techniques for Home applications

To switch between technologies, Link adaptation algorithms will be implemented (see section 3.1.3.2).

Data rates and services related to IEEE802.11 ad and ac standards have been designed in Wi-Fi cover a large amount of services mapped upon 21 usage models split into 6 categories [My,07].

Category	#	Usage Model
1. Wireless Display	1a	Desktop Storage & Display
	1b	Projection to TV or Projector in Conf Rom
	1c	In room Gaming
	1d	Streaming from Camcorder to Display
	1e	Broadcast TV Field Pick Up
	1f	Medical Imaging Surgical Procedure Support
2. Distribution of HDTV	2a	Lightly compressed video streaming around home
	2b	Compr. video streaming in a room / t.o. home
	2c	Intra Large Vehicle (e.g. airplane) Applications
	2d	Wireless Networking for Small Office
	2e	Remote medical assistance
3. Rapid Upload / Download	3a	Rapid Sync-n-Go file transfer
	3b	Picture by Picture viewing
	3c	Airplane docking
	3d	Movie Content Download to car
	3e	Police / Surveillance Car Upload
4. Backhaul	4a	Multi-Media Mesh backhaul
	4b	Point to Point backhaul
5. Outdoor Campus / Auditorium	5a	Video demos / telepresence in Auditorium
	5b	Public Safety Mesh
6. Manufacturing Floor	6a	Manufacturing floor automation

Table 3.1: WLAN usage models extracted from [My,07].

Typical data rates are listed below extracted from

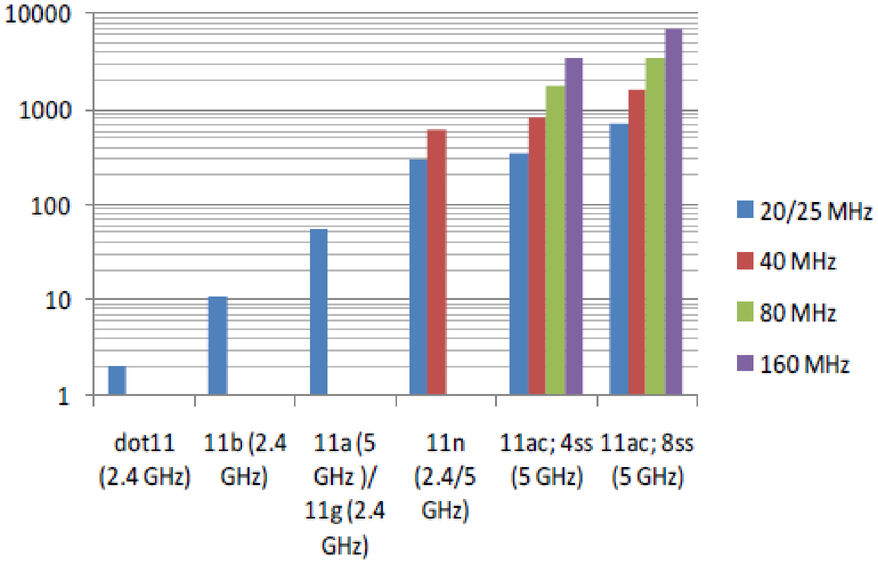

Figure 3.19: WLAN and IEEE802.11 ac data rates, figure extracted from [PS,12]

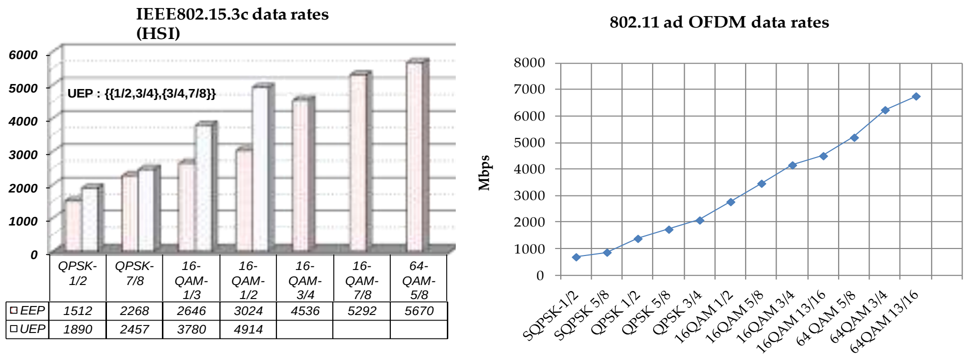

Figure 3.20: IEEE802.11 ad data rates

3.4.3.3 Technical Challenges

The key technical challenges in such scenarios are the following:

- **Multi-RAT coexistence**: Different radio technologies may be used inside the enterprise to enable wireless services inside the offices and for mobile users in the corridors: henceforth, efficient handover mechanisms are required. Multi-RAT link adaptation techniques and cross layer mechanisms have to be designed to scalably switch between technologies following RRM and Link adaptation mechanisms.
- **Green Multi**-RAT engineering : the Access point positions may be optimized to ensure QoS and service on demand whilst limiting power consumption.
- **Inter-cell Interference:** one key challenge is the presence of the inter-cell interference due to the dense deployment of small cells**.** Mm-waves small cells generate inter-cell interference amongst neighbouring apartments while different small cells present inside a given flat require interference management mechanisms to achieve the required high spectral efficiency.

The main goals in this scenario are:

- **Area Spectral Efficiency:** very high data rate may be required locally at certain moment in the enterprise for instance to download new software, hence the system has to be able to offer high area spectral efficiency to deal with this objective.
- **High QoE:** Very high data rate services such as FTTP and video streaming target static users and may have different data rate requirements in terms of capacity and latency; however, nomadic user will require mainly medium data rate services such as Voice over IP and access to the local intranet.

3.4.3.4 Synthesis

Deployment scenario	Type of deployment	Hotspot
	Outdoor / Indoor	Indoor
	Small cell/user density	High cell and user densities
	User mobility considered	Nomadic/Static
	Planned or unplanned deployments	Mainly planned
	Traffic	Video Streaming, web browsing, VoIP, etc
HetNet	Macrocell considered	Yes
	Small cells considered	Yes
	HetNet interaction envisaged	
Multi-RAT	WiFi considered	Yes
	Multi-RAT interaction envisaged	yes
Nano cell	C-RAN	Yes
	C/U Plane split	yes
	Direct mm-waves cells interactions considered through X2 like interface	yes
RAN	Frequency	Wi-Fi and LTE-A bands
	Bandwidth	Wi-Fi and LTE-A bandwidths
Backhauling	Frequency	Wi-Fi and LTE-A bands
	Bandwidth	
Fronthauling	Frequency	Wi-Fi and LTE-A bands
	Bandwidth	

3.4.4 Dense Hotspot in a Square

3.4.4.1 Generic Description

This use case focuses on a square located in the city centre where thousand of people may spend part of their daily life. The square is characterized by a several possible indoor and outdoor hotspots like bus stops, restaurants, enterprises, and recreation parks. Due to the variety this environment and the high data rate requirements for multimedia broadband services, the classic micro-waves based solutions may not be sufficient. In fact, indoor locations may suffer of poor signal strength while outdoor the inter-cell interference may strongly limit the achievable data rate.
For this dense area, the mobile operators may greatly benefit of the upgrade of their network through the deployment of mm-waves nano cells, which will enhance the quality of experience of nearby users. Static users sitting in a bar or waiting for their bus may experience real time video streaming applications, gaming, voice over IP, etc. Device to device communications can be used by a group of friends to exchange photos collected during the last weekend spent together. Furthermore, nomadic users may receive real time information on their position, which may include interactive content on nearby museums/shops as well as detailed instructions to reach their final destination in downtown.

3.4.4.2 Application and services

In the square, the following dense deployments can be considered:
• Outdoor deployment of small cell covering the square to serve the high number of users who use their devices while relaxing, waiting or traversing this square.
• Indoor deployment of small cells to serve enterprise, apartments, and shops surrounding the square.

Hence, the square and the surrounding buildings can be seen as a general case which encapsulates indoor and outdoor environments with a set of domestic, enterprise, and public areas.

3.4.4.3 Technical Challenges

The key technical challenges in such scenario are the following:

- **HetNet coexistence**: Shops/apartments/offices may deploy ad-hoc small cells and nanocells which locally create peaks of inter-cell interference. Adaptive mechanisms will be required to guarantee the required level of quality of experience.
- **Multi-RAT coexistence**: Different radio technologies may be used in this environment: intelligent offloading techniques will be required to enhance the overall wireless network capacity and permit seamless mobility.
- **Backhaul deployment:** Fiber and XDSL will be likely deployed to bring data from the core network to the indoor locations; however, wireless solutions are the best option to serve outdoor small cells and nano cells.

The main goals in this scenario are:

- **Area Spectral Efficiency:** Locally very high data rate may be required in restaurants/bars as well as at bus stops; hence the system has to be able to provide high area spectral efficiency to deal with this objective.

- **High QoE:** Advertising and GPS like services target both nomadic and static users and may have different rate requirements but generally demand very low latency; however, high data rate services can be offered to static users located in cafeterias and restaurants as well as in indoor locations.
- **Energy Efficiency:** Small/nano cells deployment will be planned with respect to peak traffic; however load in the square will be low early in the morning, medium during work-time, and high loads in the evening when people will enjoy recreation facilities nearby the square or relax at home. Energy-aware activation and deactivation mechanisms jointly with load balancing may notably improve the system efficiency while maintain locally QoS constraints.

3.4.4.4 Summary

Deployment scenario	Type of deployment	Hotspot
	Outdoor / Indoor	Outdoor
	Small cell/user density	High cell and user densities
	User mobility considered	Nomadic/Static
	Planned or unplanned deployments	Partially planned
	Traffic	Video Streaming, web browsing, VoIP, D2D, gaming
HetNet	Macrocell considered	Yes
	Small cells considered	Yes
	HetNet interaction envisaged	
Multi-RAT	WiFi considered	Yes
	Multi-RAT interaction envisaged	
Nano cell	C-RAN	Yes
	C/U Plane split	
	Direct mm-waves cells interactions considered through X2 like interface	
RAN	Frequency	
	Bandwidth	
Backhauling	Frequency	
	Bandwidth	
Fronthauling	Frequency	
	Bandwidth	

3.4.5 Mobility in the city

3.4.5.1 Generic Description

A big challenge for mobile operators is to provide high capacity inside public transportations. In this scenario, a high number of users may require access to high data rate services in a relative small indoor location that is characterized by high mobility (around 50 Km/h). People that use trams to move from home to work/the city centre may access internet to read mails, update the software of their mobiles or play videogames. Current wireless solutions do not provide the necessary capacity and reliability to deal with these requirements. In MiWEBA, we aim to investigate a novel access and backhaul architecture dedicated to public transportation able to satisfying the ubiquitous demand of data high data rate.

In particular, we aim to provide trams with 60 GHz nano cells that are capable to provide a new wireless experience to the end users during their daily traveling. Furthermore, backhaul nodes distributed on the rail ways can use mm technology to transport data towards the trams in their coverage areas.

Furthermore, the deployment of access nodes in main streets is another possible usage of line-of-sight wireless technologies to provide access to fast mobile users in cars and public transportations even if these vehicles are not provided by nanocells.

3.4.5.2 Technical Challenges

The key technical challenges in such scenario are the following:

- **Multi-RAT coexistence**: Intelligent offloading techniques will be required to permit seamless mobility to the user when accessing or leaving the trams. In the same way, when vehicles enter in main streets characterized by mm-waves base stations efficient handover from standard base station is required to experience higher quality of services.
- **Deployment:** The deployment of the backhaul nodes on the railways has to be planned to guarantee ubiquitous coverage to trams as well as high capacity. In the same way mm-based base station should be carefully deployed along the main streets to avoid unreliable services.
- **Mobility:** Mobility is a key challenge for mm-based technologies: tracking of vehicles as well inter-node coordination will be necessary to enable continuous coverage along the city.

The main goals in this scenario are:

- **High QoE:** This scenario targets users that are mainly static in their vehicle/tram; hence, the wireless network has to cope with a variety of services with different requirements in terms of jitter, latency, and data rate.
- **Cost Efficiency**: Cost effective solutions should be preferred in order to limit capital expenditure in the municipality.

3.4.5.3 Summary

Deployment scenario	Type of deployment	Hotspot
	Outdoor / Indoor	Indoor
	Small cell/user density	High cell and user densities
	User mobility considered	Static but in mobile vehicles
	Planned or unplanned deployments	Planned
	Traffic	Video Streaming, web browsing, VoIP, gaming
HetNet	Macrocell considered	Yes
	Small cells considered	No
	HetNet interaction envisaged	
Multi-RAT	WiFi considered	No
	Multi-RAT interaction envisaged	
Nano cell	C-RAN	Yes
	C/U Plane split	
	Direct mm-waves cells interactions considered through X2 like interface	
RAN	Frequency	
	Bandwidth	
Backhauling	Frequency	
	Bandwidth	
Fronthauling	Frequency	
	Bandwidth	

Table 3.2: Use cases and scenarios

3.4.6 Wireless and wired backhaul

3.4.6.1 Generic description

Wireless backhauling use cases are close to frequency bands selected to transport data rates.

Microwave solutions may be considered as well as white spaces (IEEE802.22) and wireless access technologies as detailed in the sections 2.1.3 and 3.2. Different technological solutions are available for backhauling wireless access points (WiFi, small

cells, macro cells, etc). Each solution has his advantages and drawbacks, which have to be carefully evaluated during the network planning.

Figure 3.21 shows how different technologies can coexist considering dense urban areas principally using wireless access technologies based on the one side on Hot-Spot Wi-Fi extensions and IEEE802.16j. They provide coverage in a relative small area by profiting of the different propagation conditions.

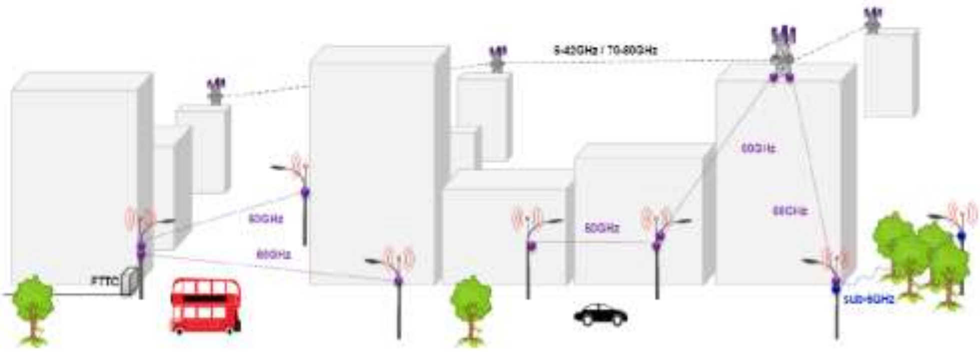

Figure 3.21: Multi RATs backhaul architecture for urban areas [SFC 2013].

For Metropolitan area covering rural and large urban areas with a medium density of communications, microwave technologies and white spaces technology as described by the IEEE802.22 standard may be considered to connect different hot spots. Each middle mile transmission is performed upon P2P transmissions restricted to LOS configurations. Middle mile data rate per link is limited to 1 Gbps.

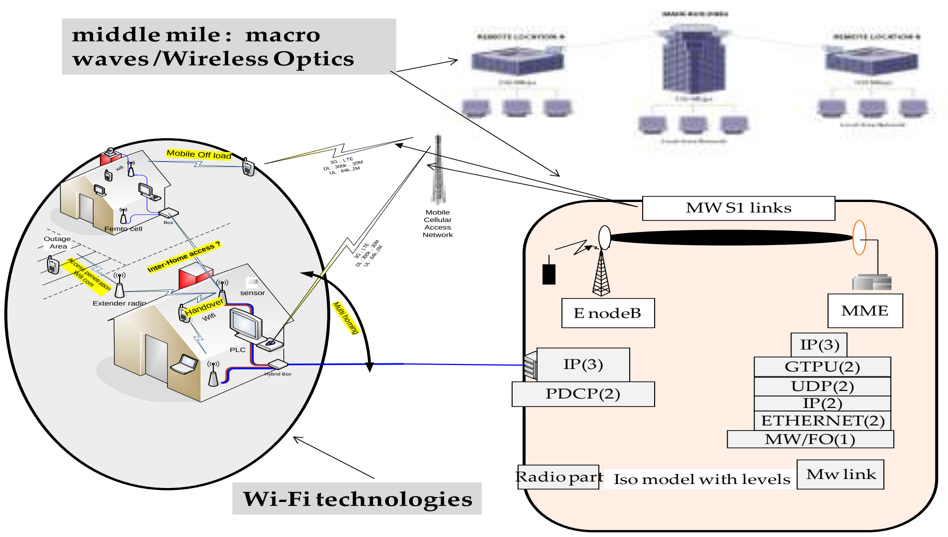

Figure 3.22: multi-techno Hot Spot Middle-Last Mile backhauling

3.4.6.2 Applications and services

Applications split into microwave and access technology are close to frequency regulations. According to the selected carrier frequency, the wireless backhaul solution will have different characteristics in term of rate, coverage, and costs [NGMN 2012, Wells2009].

- Microwave solutions <6GHz: This technology provides good coverage and possibility to operate in NLOS conditions; in these conditions the signal is able

to reach the receiver via diffraction around one or more buildings. Furthermore, the antenna does not require alignment at the installation. However, the available bandwidth is limited as most of these frequencies are already used to offer wireless access. Moreover, apart from the license exempt bands, which are highly interfered due to i.e., WiFi, the usage of sub 6GHz bands is characterized by high costs.

- 6-42 GHz: These bandwidths mainly operate in LOS conditions requiring antenna alignment for reliable transmissions. Coverage is also limited; however, these frequencies permit to realize small adaptive antennas suitable for long range transmissions. Furthermore, high capacity and low cost license are common for these backhaul technologies
- 60 GHz: Millimeter technologies that enable coverage up to 2 Km generate limited interference due to the LOS conditions and high propagation losses. However, due to large available bandwidth (up to 9 GHz), mm backhaul enables high data rate transmissions. Moreover, low cost licenses mainly characterize these bands.
- 70-80 GHz: This band enables high data rate and long range coverage. Transmissions are regulated through low cost licenses; however, the hardware design is most complex.
- FSO: Free space optic technology enables high throughput due to the large available bandwidth and is also characterized by limited costs since it operates in unlicensed spectrum. However, this technology suffers from snowfall and fog, limiting either range or availability. When transmissions face east to west, they may affected by sunlight effects.

Table 3.3 resumes the main characteristics of the wireless backhaul solutions.

Parameter	**<6GHz**	**6-42 GHz**	**60 GHz**	**70-80 GHz**	**FSO**
Data Rate	<400 Mbs	<400 Mbs	1 Gb/s	1 Gb/s	1 Gb/s
Ranges	<5 km	5 km	2 Km	3 km	200m
Spectrum License	Licensed/ unlicensed	Licensed/ unlicensed	Licensed	Unlicensed	
Costs	Medium	Medium	Low/ Medium	Medium	Low/ Medium
Other	High interference	Low interference Oxygen attenuation			High attenuation by fog and snow

Table 3.3: Comparison among mobile backhaul solutions

Table 3.4 lists RF frequency and microwave data rates related to Modulation and polarization schemes.

Modulation	RF frequency	Channel size	Polarization	PHY data rate

128 QAM	18 GHz	2 adjacent channels	V/H	Up to several Gbps
56 MHz	H+V	1.2 Gbps	V/H	Up to several Gbps
256 QAM	18 GHz	1 channel	V	1.6 Gbps
256 QAM	6.5 & 11 GHz	1 channel @40 MHz	V	400 Mbps with 2 STM1 optimized

Table 3.4: MCS, RF carrier, polarization and data rates for Mw-links

4 Conclusion

This public report summarizes architectures, scenarios and use cases associated with key technical challenges of the MiWEBA project.

Architectures provide end-to end Multi-Technology architectures integrating mm-wave components and scenarios are derived from technical challenges of the MiWEBA project, detailing key assumptions of the project split into access and front-haul backhaul scenarios. Scenarios are split into access and backhaul/fronthaul scenarios with three access sub-scenarios (indoor, outdoor, Multi-Technology Het Net scenarios) and two backhaul/front haut sub-scenarios covering P2P and PMP architectures and Mobile Multi-hop Relay Node schemes.

Use cases are derived from scenarios and provide a practical description of deployment scenarios detailing environments and applications have been designed to illustrate Multi-Technology HetNet applications.

To facilitate the development work of technical solutions with more specific research questions, the document defined six non exhaustive use cases based on the scenarios. Each such use case typically contains one or multiple fundamental challenges from several scenarios.

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