Home Networking at 60 GHz: Challenges and Research Issues

Zulkuf Genc, Bao Linh Dang, Jing Wang, Ignas Niemegeers

Wireless and Mobile Communications (WMC) Group Electrical Engineering, Mathematics, Computer Science Faculty Email: {z.genc, l.baodang, jing.wang, i.g.m.m.niemegeersg}@tudelft.nl

Abstract, *We highly believe that 60 GHz wireless technology is an ideal candidate to be the future high-speed WLAN standard for home networks thanks to its unique characteristics. In this paper, we review and present the main aspects of the 60 GHz radio regarding future home networks. We introduce the fundamental challenges with the research issues and the considerations on some promising solutions.*

Keywords: *Home networking, future home networks, 60 GHz, wireless.*

1. Introduction

The arrival of broadband communication into homes and the continuing evolution of multimedia and communication devices are increasing user demands for networked homes. The Consumer Electronics Association expects over 50% of U.S. homes will have home networks by 2008. The home network today is typically oriented to sharing of data, internet access and peripherals. The future networks, however, will be dominated by advanced multimedia applications like HDTV, IPTV, multiplayer gaming, and VoIP. The occurrence of currently unpredicted but highly demanding future applications is also quite possible. This kind of applications will bring huge amount of bandwidth and strict QoS requirements into the home networking. For example, the bandwidth required for the raw HDTV signal is about 1.5 Gbps while it is 20 Mbps for MPEG2 compressed signal. In the case of multiple HDTV streams, this need can even go beyond. Additional to bandwidth, mobility will appear as another major factor in future home networks. According to a recent survey, laptops will overtake the domination of PCs all over the world by 2011 [1]. The same survey also reveals the fact that 88% of laptop users have a wireless network at home. Looking at this picture, it can be expected that homes will mostly be equipped with wireless networks in the future and the expectations from these networks will fairly be high.

This paper basically reviews the 60 GHz wireless technology regarding home networking. It discusses the challenges and the research issues in utilization of this technology for future home networks. The rest of the paper is organized as follows. Section 2 gives the motivation and background for 60 GHz. Section 3 explains a typical use case scenario for a future home network at 60 GHz. Two architectural approaches for home networking at 60 GHz will be presented in Section 4. Section 5 discussed the challenges and research issues. Finally, Section 6 concludes the paper.

2. Motivation and Background

Today's WLAN technologies are not mature enough to support the high expectations for the future home networks. These expectations even do not look like achievable on the roadmaps of existing 802.11x and UWB according to GIT professor Laskar [2]. The IEEE 802.11n, which is still under development as the latest version of 802.11 series, is expected to offer only 100-200 Mbps of actual throughput [3]. On the other hand, specification activities of WirelessHD group towards the next generation wireless digital network interface for consumer electronics and PC products aim to achieve data rates from 2 Gbps to 20 Gbps [4]. SiBeam Inc. recently introduced a new technology for the production of WirelessHD compliant chips for multi-gigabit high definition video and audio distribution in short range [5]. A research group from GIT has already achieved data-transfer rates of 15 Gbps at a distance of 1 meter and 5 Gbps at 5 meters [6]. All these achievements have been made by the utilization of 60 GHz radio. The promising characteristics of 60 GHz radio promote it as the best candidate technology for future gigabit wireless LANs. The most outstanding attribute of 60GHz is 5 GHz continues block of bandwidth in the globally license-free spectrum between 59-64 GHz as seen in Fig. 1. The unique oxygen absorption band at 60GHz also enables the transmission at higher power levels, up to 40 dBm in U.S. and Europe, 10dBm in Japan, than 802.11x and UWB standards. This huge amount of available spectrum and high power levels allow the data transfer at the rate of gigabits per second over indoor distances. The transmission distance, however, is mainly determined by the location of the walls in a typical home. 60 GHz radio signals can not penetrate walls due to heavy attenuation. This characteristic turns each room into a separate cell, in which the use of the whole system capacity is possible. The frequency re-use here helps the network to achieve higher throughput by preventing medium contention and collisions. The naturally isolated cells created by high oxygen absorption and heavy attenuation also form a very secure network environment. Additionally, radios operating at the higher frequencies inherently become more directional and require smaller antennas with narrower beams. These directive antennas can better focus their energy in the transmission direction by minimizing the interference and interception possibility. As for the health concerns, 60 GHz radio does not pose a risk to human health since its signals can not penetrate through human skin into the body [6]. The allowable radiation power limits for 60 GHz are also much lower than the safety levels determined in the studies [7]. Some early critics of 60 GHz technology were generally pointing out its implementation cost. However, recent advances showed that it is possible to produce low-cost CMOS circuits operating at 60 GHz [6, 8]. These advances together with promising features of 60 GHz have leaded the standardization activities. IEEE has formed 802.15.3c study group to develop a millimeter-wave-based alternative physical layer (PHY) for Wireless Personal Area Network (WPAN) [9]. Ecma International has also started to develop an international standard for 60 GHz short range communications to utilize it at bulk data transfer, high-definition multimedia streaming and WPAN applications [10].

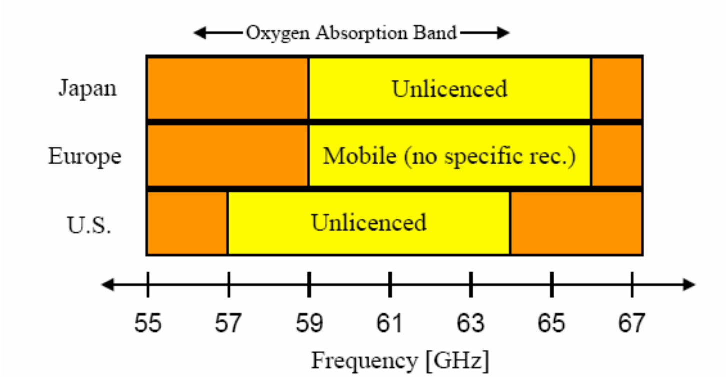

Figure 1: 60 GHz spectrum allocation

3. Use Case Scenario

The High-Definition Television (HDTV) and the Ultra High Definition Video (UHDV) are leading a revolution of home entertainment experience. The trend is being pushed towards such an emergent future home environment, where people are going to be surrounded by high capacity multimedia devices. Those devices can either be the fixed household devices like LCD and DVR or wall-mounted HDTV plasmas, or the personal portable devices such as Laptop, video game consoler and DVD-player for the next generation DVD technologies such as HD-DVD or Blue-Ray. The establishment of multi-gigabit links between these devices will enable the easy and quick delivery of high-definition content without the confusion and unaesthetic view of cables. One example would be a storage device servicing HD video and audio to a HDTV in the vicinity and simultaneously to another one locating in a different room. In the presence of wireless connectivity, people will be free to move around the rooms with their mobile devices by keeping the active multimedia sessions on them without any interruption. The multimedia sessions will also be able to follow a mobile user from one device to the other one in the vicinity of the user. Beside the home networking capabilities, the high-speed wireless connectivity will allow seamless, easy and uninterrupted access to the bandwidth-intensive broadband services as well. People will enjoy these services in the comfort of their homes by ensuring the privacy and security of their home network.

The realization of such a scenario described above will certainly draw more consumers into home networking. In response to this interest, more advanced services and applications can be expected to growingly take place in the market. The key point in this phase will be the availability of a future-proof wireless technology, which will meet the requirements of the desired home network, like enormous bandwidth need (multi-Gbps), simplicity, tight QoS necessities and security. The existence of such a technology can also help overcome the problem of interoperability. We believe that 60 GHz technology can play this role in future home networks once it becomes standardized and gains more maturity.

4. Communication Infrastructures

In order to ensure the full radio coverage at 60GHz within the entire house and the best in-home connectivity between any communication devices, either fixed or mobile, home network communication infrastructure should be designed and be deployed not only to provide high-bandwidth 60GHz radio communication links inside a room, but also to use dedicated equipment and devices to cross walls, connect rooms and reach gateways for connection to access networks. Further taking into account of flexibility and economy in architectural and interior design, the candidate communication infrastructure should at the best eliminate the huge amount of cabling - initial, refitted and extended - in the house, and allow itself being integrated into the user ecosphere in a unobtrusive and aesthetic manner.

We envision two possible infrastructure approaches for home networking by considering the 60GHz radio characteristics. One is to use a mixed wired and wireless infrastructure as shown in Fig. 2.a, i.e. Radio-over-Fiber (ROF) technique [11], which deploys fibers to connect rooms, and put simple antennas at the end of the fiber to emit radio signals to form individual 60GHz radio cells The other approach is to deploy purely wireless infrastructure as in Fig. 2.b, where the network devices are connected in ad hoc manner, with necessary radio relay devices deployed We believe these two candidates are complementary in time frame for market introduction and capabilities.

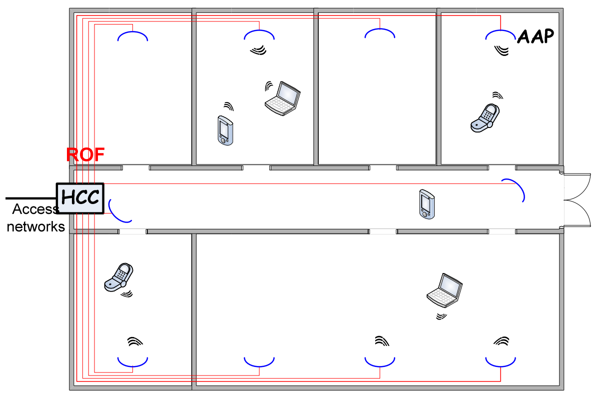

Figure 2.a: Cell-based Home Network Communication Infrastructure

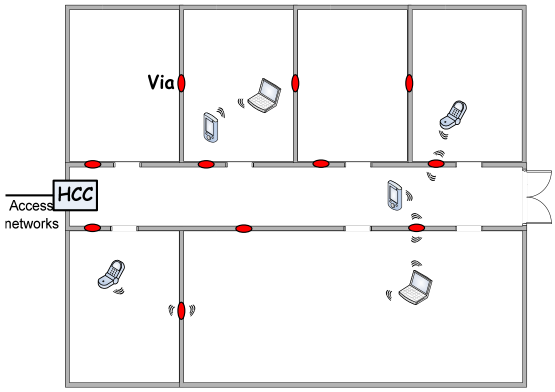

Figure 2.b: Adhoc-based Home Network Communication Infrastructure

4.1 Cell-based Communication Infrastructure

This approach is based on the novel Radio-over-Fiber (RoF) technique, which requires a low-cost plastic optical-fiber infrastructure to be installed in new buildings or retrofitted to existing buildings. Two essential infrastructural elements are:

- The Home Communications Controller (HCC). The concept evolves from the prevailing residential gateways such as a DSL access gateway or a cable set-top box. Besides the gateway functions of interfacing between home network and the access networks, it should be implemented with the full network stack functionality and additional control and management units as the central intelligence of the network.
- The Antenna Access Points (AAPs). They are the wall-socket access points, which can be considered as dumb antenna devices only with layer-2 functionality for interfacing the radio signals.

The fiber infrastructure forms a tree with the HCC at the root, and with the AAPs at the tips. In each room at least one AAP is deployed, and thus at least one short-range 60GHz radio cell is formed potentially superimposed to offer 60GHz connectivity. For uplinks 60GHz signal from the source device is picked up by the AAP in the close vicinity, modulated as ROF microwave signals, and guided to the HCC. At the HCC, the incoming signal is converted to the proper optical frequency and routed to the AAP close to the destination device, where the signal is modulated once again into 60GHz radio as the downlink traffic. The interroom connectivity provided by this infrastructure can thus in principle provide 60GHz radio connectivity cross the entire house.

4.2 Adhoc-based Communication Infrastructure

As an alternative of installing optical fibers, this approach makes use of microwave transponders, or radio relays, pasted on the walls and radiating RF signals across it. The only infrastructural elements required are the HCC and the wall-mounted radio transponders, the so-called Via devices (Via-s). This approach does not require a backbone network to interconnect the room-based cells. It basically forms an in-house ad-hoc network, with a subset dedicated infrastructure nodes, Via-s, which typically have the known fixed locations. In this case, the HCC still serves to connect home network to the access networks, however it is most likely that it won't be the only device implemented with sophisticated control and management units due to the dynamic and distributed nature of ad-hoc networks. Therefore we must seek a solution to distribute network intelligence among, if not all, a subset of network devices.

5. Challenges and Research Issues

Despite the provision of multi-Gb/s data-rates, networking at the 60 GHz band exposes some serious challanges that prevent the adoption of this frequency band in the range of Local Area Networks (LAN). In this section, the challenges of networking at the 60 GHz band and their research issues are discussed.

5.1 Connectivity

As mentioned in previous sections, the propagation of signals at 60 GHz is strongly weakened by surrounding obstacles and walls. Concrete walls can be considered as reliable cell boundaries since they can attenuate signals as much as 40 dB. A person standing in between a line-of-sight connection can also take 20 dB away from the link budget. To further analyze the coverage at 60 GHz band, a simulation study has been carried out using a race-tracing tool called Radio-Wave Propagation Simulator [12]. This simulator has been shown to be accurate in terms of statistical properties [13]. Fig. 3 illustrates the simulated in-home environment containing multiple small rooms (5*8m), a large room (15*8m) and a corridor. Immobile people and objects such as sofas, tables etc. were placed onto the floor. In the first simulation scenario, an omni-directional antenna with 0dBm of transmission power is placed in the center of each room at the height of 3m. The antenna placed in the big room has 3dBm antenna gain. Two others omni-antennas are placed in the corridor. Signal strength is recorded at the height of 1.5m.

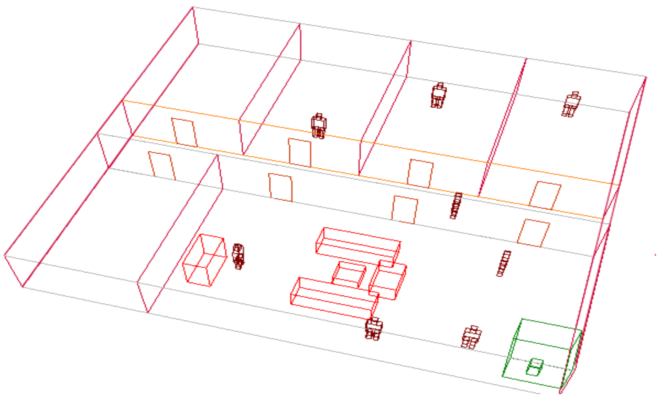

Figure 3: The simulated in-home environment

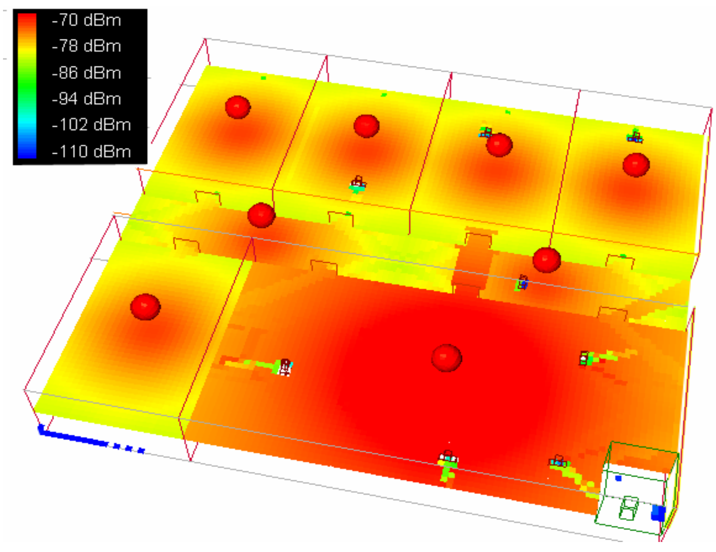

Figure 4: Signal Coverage at the 60 GHz frequency band

Fig. 4 shows the simulated signal coverage of the first scenario. As predicted, the transmission of 60 GHz signals is severely effected by shadowing. Not only can large objects such as trees, furniture etc. cause shadowing, but even a person can completely block the signal. Thus, to achieve the full connectivity in a crowded room is rather challenging by this deployment. Moreover, a number of antennas are required to cover the long corridor.

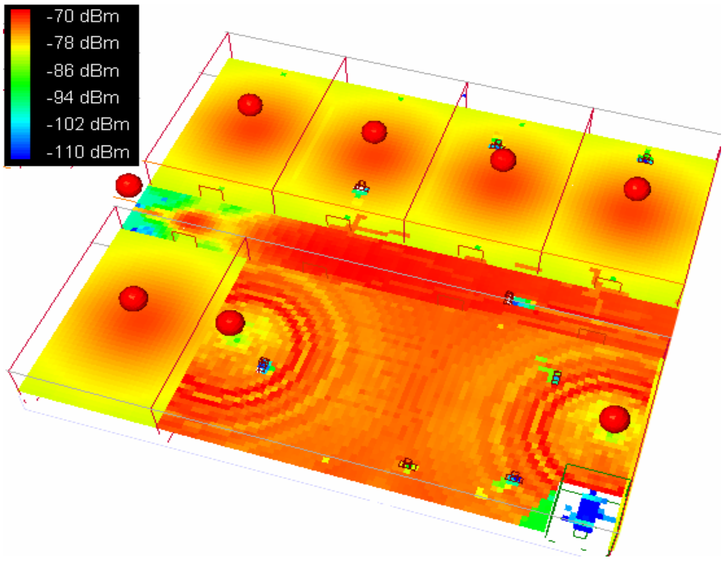

Figure 5: Signal Coverage at the 60 GHz frequency band – Multiple antennas

To improve the signal coverage in the big room, two Dielectric Lens antennas are deployed for the big room in the second scenario (Fig. 5). As a result, the signal coverage is significantly improved. A large part of the shadowed areas behind the people has been removed. In this paper, the use of multiple antennas to improve signal coverage is referred by the term "Antenna Redundancy". Another option to overcome the line-of-sight limitation of 60 GHz propagation is to make use of smart antennas. Since the antenna dimension is inversely proportional to the operating frequency, it is possible to deploy many antennas in a small fixed area. The antenna array formed by these small antennas can intelligently adjust the gain, the transmission power and the beam direction according to the link conditions. For example, if any obstacle blocks the line-of-sight path of the radio wave, a smart antenna array can use the reflections by redirecting the energy onto the reflecting objects [14]. However, these techniques are not enough to create a reliable WLAN covering whole-home since walls are still impassable barriers for 60 GHz radio signals. New methods and devices are required to overcome this problem.

5.2 Mobility

Another problem arose is the directional overlapping areas between cells. As can be seen in Fig.6, overlapping only exists around the opened areas, i.e. opened doors and windows.

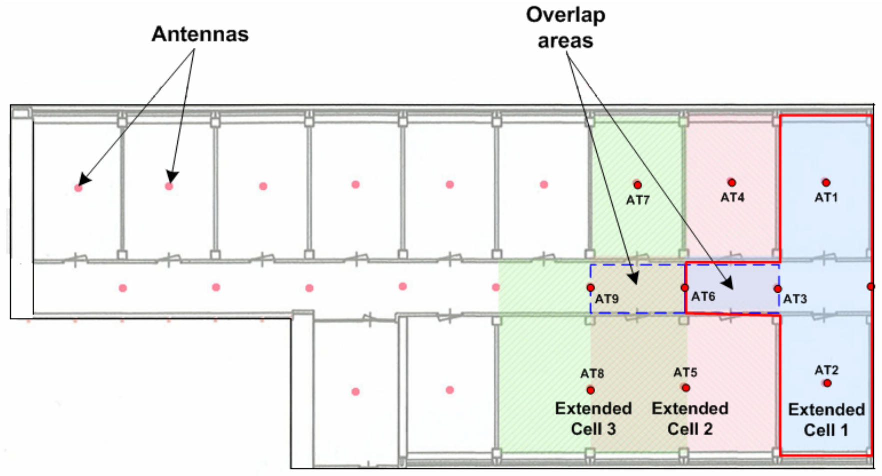

Figure 6: The Extended Cell (EC) Concept

Consequently, overlapping areas are often narrow and directional. In a multi-channel communication system, where handovers (HO) are required when a Mobile Station (MS) roams from one cell to another, these overlapping areas might be too small to allow an MS sufficient time to trigger and complete a handover. In this paper, we use the term "corner effect" to refer to this problem. The directional overlapping poses difficulties on the design of the mobility handling mechanism, since the transition between two cells is too sharp and short to trigger a handover. This problem gets worse as mobile users in an in-home environment are much likely to perform sharp-turns while moving from one room to another. To perform a Radio-Signal-Measurement (RSM) based handover, a good decision has to be made based on the signal strength averaging and hysteresis margin. In order to guarantee a seamless communication environment, it therefore requires a minimum overlapping area between two adjacent cells. In other words, a mobile station must be able to listen to both APs, so it can determine which one is better to connect to. In [15], the relation between the minimum overlapping area and the handover frequency defined by the ratio between a mobile user's velocity and the cell size has been carried out. As calculated in the paper, the minimum overlapping area for an indoor environment is 20% of the cell's diameter (2 meters). It is therefore crucial that large enough overlapping areas are created in the system in order to guarantee a seamless communication environment.

With this target in mind, an infrastructure for broadband in-building networks at millimeter-wave GHz band was presented in [11]. It is proposed to group multiple adjacent antennas into an Extended Cell (EC) and to allow the antennas to transmit the same content over the same frequency channel. Moreover, an EC is designed to cover several adjacent rooms and a part of a transitional area. By doing so, an overlapping area between two ECs can always be created in the transitional zone, and thus seamless communication can be achieved as mobile users always have to pass a transitional area in order to move from one room to another (Fig. 6). Using this concept, the corner effect is mitigated as a mobile user does not have to perform a HO as long as it is still in the EC. The number of HOs will therefore be substantially decreased. Furthermore, a form of spatial diversity can also be achieved with the EC concept since multiple copies of a signal are concurrently sent by all the antennas in an EC. Shadowing is reduced since there is a better chance that a mobile station receives a good signal. To illustrate the effectiveness of the EC concept, simulations have been carried out. The simulation setup was described in [11]. The simulation results in Fig. 7 clearly show the improvement in terms of the average number of drop calls when the EC concept is employed. However, since a call lasts longer, the average number of HOs per call also increases. As a result, a tradeoff should be made between the average EC size and the required quality of service in terms of drop calls.

This EC concept connects well with the Antenna Redundancy ideas and the RoF infrastructure approach presented in Section IV.a. New antennas can be easily connected to the optical infrastructure to improve the signal coverage. Moreover, these new antennas will be included into the existing extended cell.

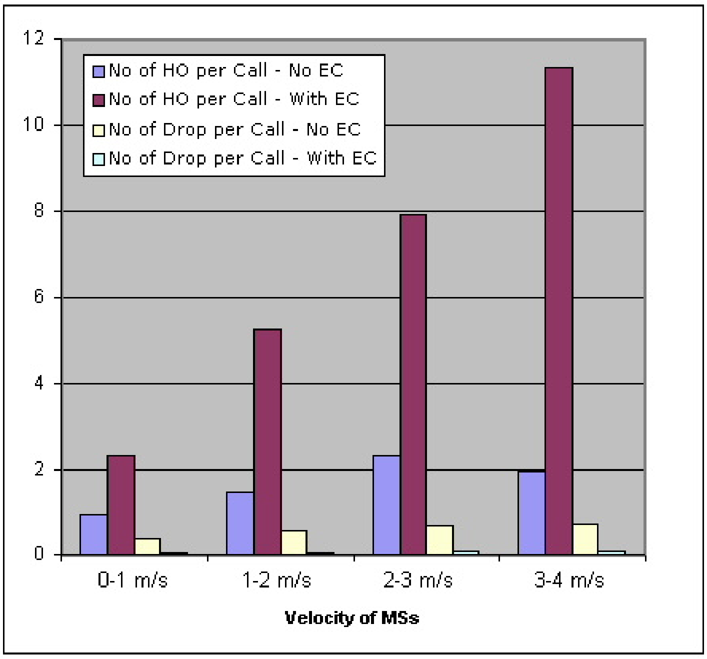

Figure 7: Average number of HOs and Call Drops

5.3 Self-configuration

60GHz radio, while offering great opportunity to prosper versatile bandwidth-demanding home applications, raises greater challenges to realize self-configurable home networking systems. The particular short radio range and vulnerability for line-of-sight obstruction result in frequent changing on link quality and network topology, and thus require a large amount of reconfiguration processes. As the 60GHz radio promises for high data rate and real-time applications, the timeliness of the reconfiguration processes is especially demanded, as it is directly tied to the user perception quality.

Self-configuration is essentially an important issue of network control and management at different connectivity levels (i.e. Physical and Link-, Network- and service level) to enable distributed application entities that spread over the home network components to cooperate for a particular application. While the Network- and service levels self-configuration processes (i.e., addressing, route discovery, service discovery, etc.) have great generality for all radio technologies, the novelty of 60GHz radio calls for special concerns on Physical and Link level self-configuration process. An example with the cell-based communication infrastructure is when the number of users or terminals in a room (e.g., a meeting room) becomes so large that the picocell capacity cannot guarantee the required service quality, the self-configuration process should automatically add extra resources, e.g., establish an extra picocell by turning on an additional wavelength in the fiber to that room, and handing-off part of the load to that new picocell. For Ad-hoc based approach, frequent disturbances of LOS communication links (e.g., people standing in LOS links) require fast resource discovery strategy to re-establish connectivity. Self-configuration is thus required to efficiently organize devices into piconets and scatternets to support multihop connections. Such process must be established for supporting the cooperation between distributed devices, and be tailored for 60GHz radio with respect to the use of directional antenna, LOS links and thus the specialty of the MAC protocol.

Although most current contributions related to self-configuration issue have been focusing on developing and optimizing isolated layer-dependent protocols, we share a vision with the new networking paradigm such as autonomic communications [16], and are seeking a promising way to cooperate different level configurations under a cross-layer optimization strategy, in the sense that the configuration information at different levels may be mutually beneficial. However, as pointed out in [17], cross-layer approach should not only focus on the layer-wise performance enhancement blindly, but rather be guided by the high-level goal required by the applications.

To solve the potential confliction among configuration actions at different layers, a promising way is to employ a general management module to conciliate self-configuration processes in parallel threads, rather than merely increase complexity to achieve local sophistication within individual configuration protocols. Such a self-configuration management module is expected to incorporate three basic functions: (1) information abstraction to aggregate the contextual information from different connectivity levels and to define configuration states of the network; (2) configuration coordination to optimize configuration processes under an overview of the configuration states and under joint consideration and decision of all connectivity levels; and (3) protocol interface to exert the decision from the configuration coordinator to adjust and operate the layer-based configuration protocols. This management module should be implemented in the capable devices in terms of computation, storage and power resources, whilst taking into account the location and mobility. By deploying the cell-based communication infrastructure, as all the traffic goes through the HCC, it should at the best take the role of the self-configuration manager, and forms a centralized management structure. For the ad-hoc based approach, besides the HCC, other capable devices should also be implemented fully or partially the module to provide distributed management. In this way, hierarchical self-configuration management can be organized.

5.4 Cognitive Networking

As the deployment of 60GHz results in a more dynamic and distributed home networking environment, control and management of such networks stringently require the efficiency of the processes. That means on one hand, the timeliness is highly desired for configure and adapt the 60GHz applications to a user desired state. In particular for personal applications, the maximum allowed configuration time is determined by the patience of the user (often of the order of a second). On the other hand, necessity of re-configuration and adaptation processes must be decided on occurrence of the networking state changes, in other words, whether and when a re-configuration process should be triggered. This is critical to achieve a stable networking system, which shields the network dynamics from its users. With further concerns on building home network to be a "self-" capable system, the network should be able to identify its goals centered on its users' need and manage on its own to realize those goals regardless the heterogeneous, distributed and dynamic network environment. This requires new mechanisms to evoke the expert-like intelligence on the network.

One promising solution to tackle such challenge is to incorporate the novel concept of cognitive networking into play. Being specified in [18], a cognitive network has a cognitive process that can perceive current network conditions, and then plan, decide and act on those conditions. The network can learn from these adaptations and use them to make future decisions, all while taking into account the user experience. With the ability to learn from the consequences of the network operations and to accumulate experience on executing such operations effectively and efficiently, the cognitive network is expected to switch network control and management processes from a reactive to a proactive manner. More specifically, the experience can help, for example, to predict when a reconfiguration/adaptation will be needed to start ahead of time. The idea is based on the observation that in-home usage of the network exhibits a lot of patterns over time. An example would be the daily routine of inhabitants of a house, who repeat the same patterns of behavior and, movement from room to room.

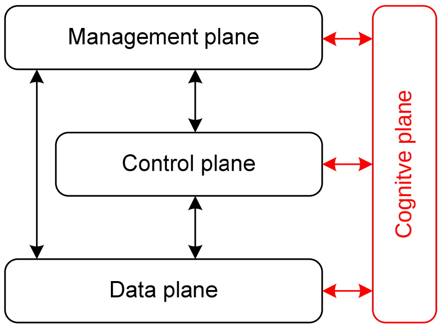

Figure 8: FHN architecture: a view of plane division

Inspired by the idea of constructing a knowledge plane for the Internet [19], the architecture of the cognitive home network is expected to have a Cognitive Plane (CP). In our opinion, the CP is best to be positioned a vertically cross all the other three existing planes (e.g. data-, control- and management planes) as shown in Fig.8. The purpose has two fold. One is to help with sophisticated decision-making for high level instruction. This mainly works for the management plane and control plane to realize network self-management. The other one is for knowledge circulation. Knowledge aggregation and distribution need to be carried out by data plane, while the control and management planes should be responsible for admission of knowledge accessing and provision. Within the CP, four basic functionalities are proposed and will bear further deliberation: (1) a monitoring function perceives environment and collects meta-information from the users, the network, and the environment in which the network operates, from which user patterns and context can be derived; (2) a learning function processes and converts the aggregated information, extracting, adjusting and correcting patterns and deriving context to form the basis for predicting the next services demanded from the network operations; (3) a decision function initiates proactive configuration and reconfiguration, based on learned patterns and context through specific cognitive techniques; (4) an execution function takes decisions made from the decision function and exerts them into actions upon network operation. A key question is how to identify the most applicable cognitive techniques for certain network control and management operation. This should be answered from a joint effort of telecommunication and artificial intelligence expertise. Further we need to identify which information needs to be sensed and what the context consists of. We can build here on work that has been done in context-aware computing and networking [20] and work on ambient intelligence [21]. Although the concept of cognitive networking has illuminated a research direction for realizing network intelligence, the additional cost (e.g. system complexity, power consumption, etc.) by introducing such a new network structure should not be ignored. Introduced in [22], the prices of anarchy, ignorance and control can be considered as further evaluation of the necessity and fitness of adopting cognitive network as the solution for certain problems.

6. Conclusion

In this paper, we review and present the main aspects of the 60 GHz radio regarding future home networks. We also introduce the fundamental challenges with the research issues we are currently working on. With regards to connectivity, antenna redundancy can be a solution for the shadowing caused by immobile and mobile obstacles. This solution is not costly when combined with ROF since the antennas are connected to the existing optical fiber infrastructure and they are very simple. Another promising solution to this problem looks like deployment of smart antennas. To overcome the corner effect and guarantee a seamless communication, the EC concept can be used. For the self-configuration concerns, we consider to employ a general management module operating across the layers. Finally, we investigate the cognitive networking paradigm and its application to the problems of future home networking.

7. Acknowledgement

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