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Home networking at 60 GHz: challenges and research issues

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Abstract The recent developments in CMOS technology are about opening a new exciting door to affordable 60-GHz radio applications. One promising application area for 60-GHz radio is home networks in which there is an increasing demand for multi-gigabit wireless networking. The research efforts so far have generally focused on utilizing the 60-GHz band for point-to-point communication by addressing its physical aspects like propagation characteristics and channel models. The issues of 60-GHz networking at the system level have not been adequately considered. In this paper, the challenges and the research issues of 60-GHz networking are reviewed from the system-level perspective. We present them in the context of wireless local area networks for future home networks with discussions on some possible solutions for the introduced challenges.

Keywords Home networking · 60 GHz · Future home networks · 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 that more than 50% of US homes will have home networks by 2008. A home network of today is typically oriented to sharing of data, internet access, and peripherals. The future networks, however, will be dominated by advanced multimedia applications like high-definition television (HDTV), Internet protocol television (IPTV), multiplayer gaming, voice-over Internet protocol, etc. The occurrence of currently unpredicted and highly demanding future applications is also quite possible. This kind of applications will demand huge amount of bandwidth and pose strict quality of service (QoS) requirements on the home networking. For example, the data rates required for raw and MPEG2 compressed HDTV streams are about 2 Gbps and 20 Mbps, respectively. In case of multiple HDTV streams being concurrently played, the bandwidth to support the required data rates will be much higher.

Additional to bandwidth, mobility also appears as another major factor shaping the 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 reviews the 60-GHz wireless technology from a future home networking perspective. It discusses the challenges and the research issues that need to be addressed in order to successfully deploy this millimeter wave band for wireless local area networks (WLAN). Moreover, potential solutions for addressing the presented challenges are also discussed in this paper. We show that it is possible to design and deploy a full size WLAN operating at 60 GHz in a home environment.

The rest of the paper is organized as follows. Section 2 elaborates on the motivations and background information for the 60-GHz band. Section 3 explains a typical use case

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scenario for a future home network operating at 60 GHz. Two architectural approaches for home networking at 60 GHz will be presented in Section 4. Section 5 discusses the challenges and research issues. Finally, Section 6 concludes the paper.

2 Motivation and background

Today's WLAN technologies are not capable of supporting the high expectations for the future home networks. These expectations even do not look achievable on the roadmaps of existing 802.11x and UWB [2]. The IEEE 802.11n technology, 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, the standardization 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 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 m and 5 Gbps at 5 m [6]. All these achievements have been made by the utilization of 60-GHz radio band. It has a 5-GHz block of bandwidth in the globally license-free spectrum between 59 and 64 GHz as seen in Fig. 1.

The unique oxygen absorption band at 60 GHz also enables the transmission at higher power levels, up to 40 dBm in the USA and Europe and 10 dBm in Japan, than the IEEE 802.11 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. Sixty-gigahertz radio signals cannot penetrate walls due to the heavy attenuation. This characteristic turns each room into a separate cell in which the use of the whole system capacity is possible. Similar to cellular networks, frequencies can be reused here to help the network achieve higher throughput. The naturally isolated cells created by high oxygen absorption and heavy attenuation also form a very secure network environment. Additionally, radio signal transmissions at the higher frequencies inherently become more directional and require smaller antennas. These 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 cannot 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]. Indeed, a research group from Melbourne University has even demonstrated a working transceiver integrated on a CMOS chip that operates at 60 GHz [9]. It is expected to cost less than $10 to the manufacturers. These advances, together with promising features of 60 GHz, have led the standardization activities. IEEE has formed 802.15.3 c study group to develop a millimeter-wave-based alternative physical layer (PHY) for wireless personal area network (WPAN) [10]. Ecma International has also started to develop an international standard for 60-GHz short range communication to utilize it at bulk data transfer, high-definition multimedia streaming, and WPAN applications [11].

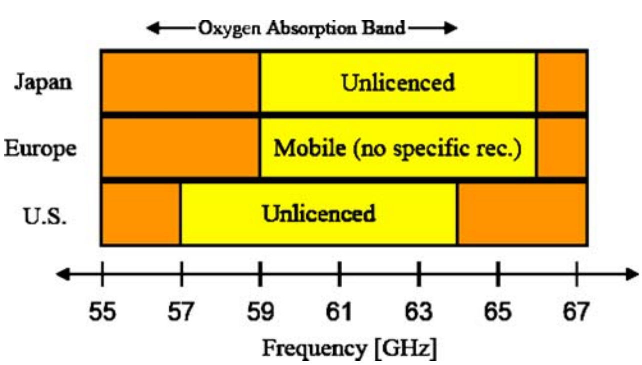

Fig. 1 60-GHz spectrum allocation

3 Use case scenario

HDTV and the ultra high-definition video 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 like Blue-Ray. The establishment of 60-GHz 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. Moreover, these multi-gigabit links will eliminate the need for compression of the high-definition content. The uncompressed data transfer will enable the production of lower cost higher quality video products which are free of compression and decompression equipments.

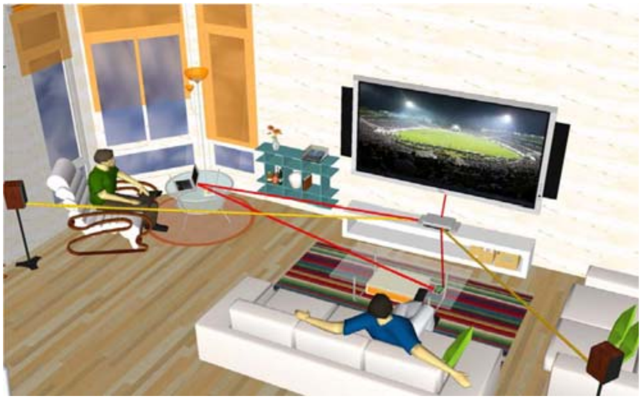

Fig. 2 A use case scenario demonstrating the high-definition content sharing and distribution via 60-GHz links

One highly possible use case scenario could be a simple network for high-definition content sharing and distribution between end-user devices such as the storage device, HDTV, laptop, handset devices, and speakers as seen in Fig. 2. Thanks to 60-GHz links, the user can transfer the HD video content of a football game, which he downloaded into his handset from a public kiosk in the stadium right after the game, to the storage device in seconds. While the high-definition video content is shown on the HDTV via 60-GHz link, the audio is distributed to speakers via 60 GHz or a lower frequency radio. At the same time, another user can download this content into his laptop in a few seconds.

Apart from this specific scenario, in the presence of wireless connectivity, people will be free to move inside the home with their mobile devices by keeping the active multimedia sessions on them. The multimedia sessions will also be able to follow a mobile user from one device to another around the user. Besides 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 scenarios 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 guarantee the full radio coverage at 60 GHz within the entire house, the home network communication infrastructure should specially be designed by ensuring the dependability of highly sensitive 60-GHz links all over the house. Considering the flexibility and economy of architectural and interior design, the candidate communication infrastructure should, at the best, eliminate the enormous amount of cabling in the house and allow itself to be integrated into the user ecosphere in an unobtrusive and aesthetic manner.

We envision two possible infrastructure approaches for 60-GHz home networks by taking into account the radio characteristics of this band. One is to use a wired and wireless infrastructure mix, as shown in Fig. 3a, which deploys fibers to connect rooms, and put simple antennas at the end of the fiber to emit radio signals to form individual 60-GHz radio cells. The other approach is to deploy purely wireless infrastructure, as in Fig. 3b, where the network devices are connected in ad hoc manner, with dedicated devices relaying the 60-GHz radio signals through the walls.

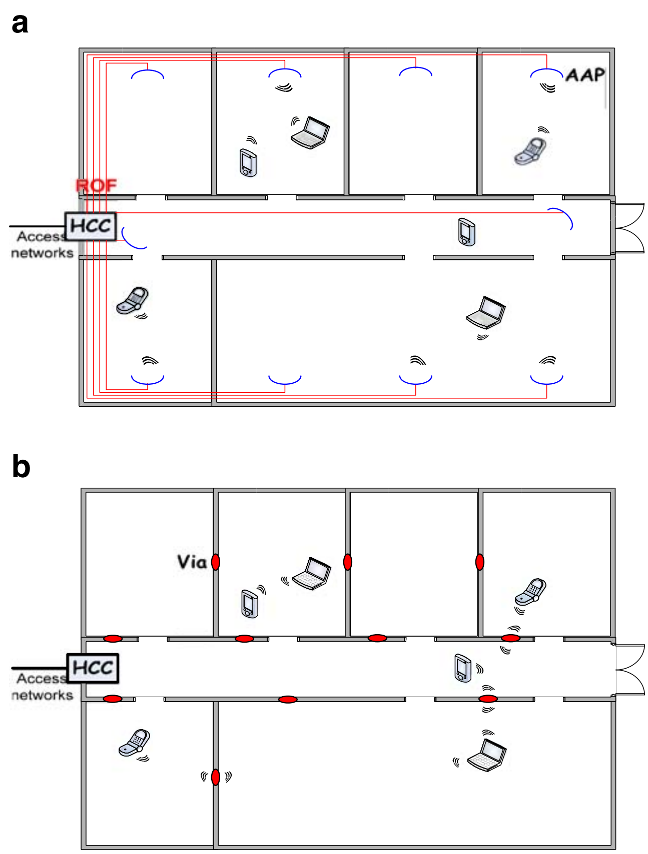

Fig. 3 **a** Cell-based home network communication infrastructure. **b** Ad-hoc-based home network communication infrastructure

We believe that these two candidates are complementary in timeframe for market introduction and capabilities.

4.1 Cell-based communication infrastructure

This approach is based on the novel radio-over-fiber (RoF) technique [12] which requires a low-cost plastic optical fiber infrastructure to be installed in new buildings or retrofitted to existing buildings. As illustrated in Fig. 3a, there are two essential infrastructural elements. The first one is the home communications controller (HCC), a concept which 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 the home network and the access networks, it will be implemented with the full network stack functionality and additional control and management units as the central intelligence of the network. The other infrastructural element is the antenna access point (AAP). It is a wall socket access point which can be considered as a dumb antenna device 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 60-GHz radio cell is formed potentially superimposed to offer 60-GHz connectivity. For uplinks, 60-GHz 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 60-GHz radio as the downlink traffic. The inter-room connectivity provided by this infrastructure can thus, in principle, provide 60-GHz radio connectivity crossing the entire house.

4.2 Ad-hoc-based communication infrastructure

In order to completely free the future home networks from cabling, the ad-hoc-based approach aims to investigate a new type of 60-GHz radio relaying device. This device is considered as two pieces which can be attached to each side of a wall to relay the 60-GHz signals from one side to other one. The idea here is based on the fact that a loss of 10–20 dB through the wall can be compensated by attaching a transmitter on one side of the wall and increasing the transmission power with either a power amplifier or a phased antenna array. Referring to the experimental results in [13], 10- to 20-dB gain is able to compensate the penetration loss of 60-GHz radio through most common wall materials (e.g., brick, glass, wooden board, etc.). Thus, by attaching a receiving antenna on the other side of the wall, it is feasible to catch the signal with enough signal strength.

In this approach, the only infrastructural elements required are the HCC and the wall-mounted radio transponders, which we call as “via” devices (Via-s). A 60-GHz home network with the Via-s does not need a backbone network to interconnect the room-based cells. Instead, it basically forms an in-house ad hoc network with all the Via-s by connecting the devices in different rooms over them. In such a network, the HCC serves to connect home network to the access networks. However, HCC is not considered being the only device here having control and management functionalities as in the cell-based approach. We envision a solution distributing these functionalities with network intelligence among, if not all, a subset of Via devices to better adapt to the dynamic and distributed nature of such an ad hoc network.

5 Challenges and research issues

Despite the provision of multi-Gbps data rates, networking at the 60-GHz band exposes some serious challenges that prevent the adoption of this frequency band in the range of 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, in an indoor environment, 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 [14]. This simulator has been shown to be accurate in terms of statistical properties [15]. Figure 4 illustrates the simulated in-home environment containing multiple small rooms (5×8 m), a large room (15×8 m), and a corridor. Immobile people and objects such as sofas, tables, etc. were placed onto the floor. In the first simulation scenario, an omnidirectional antenna with 0 dBm of transmission power is placed in the center of each room at the height of 3 m. The antenna placed in the big room has 3-dBm antenna gain. Two others omni-antennas are placed in the corridor. Signal strength is recorded at a height of 1.5 m.

Figure 5 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

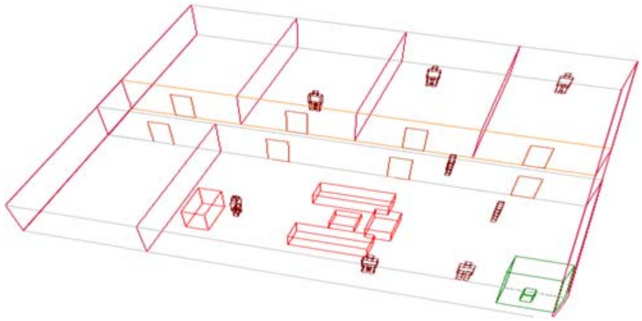

Fig. 4 The simulated in-home environment

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. To improve the signal coverage in the big room, two dielectric lens antennas are deployed for the big room in the second scenario (Fig. 6). 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

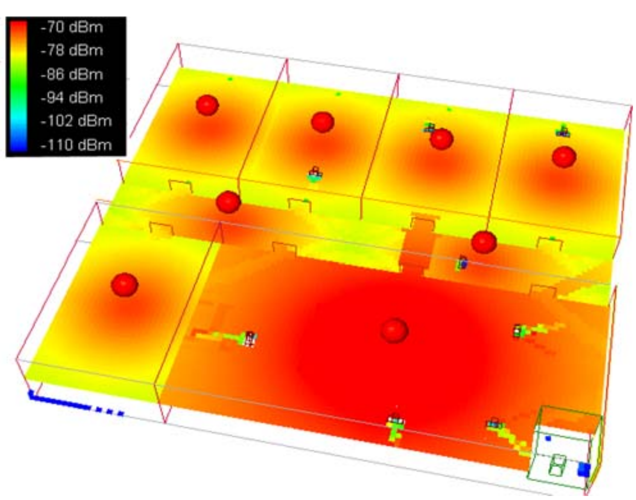

Fig. 5 Signal coverage at the 60-GHz frequency band

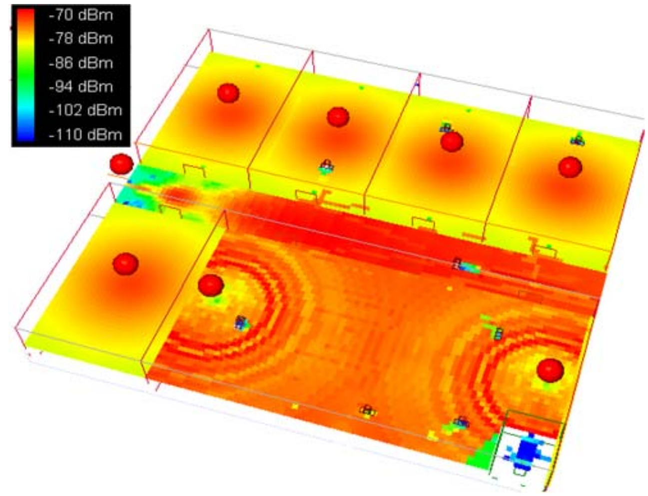

Fig. 6 Signal coverage at the 60-GHz frequency band—multiple antennas

objects [16]. 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 that arose is the directional overlapping areas between cells. As can be seen in Fig. 7, overlapping only exists around the opened areas, i.e., opened doors and windows.

Consequently, overlapping areas are often narrow and directional. In a multichannel 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-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 [17], the relation between the minimum overlapping area and the handover frequency defined by the ratio between a mobile user's velocity and

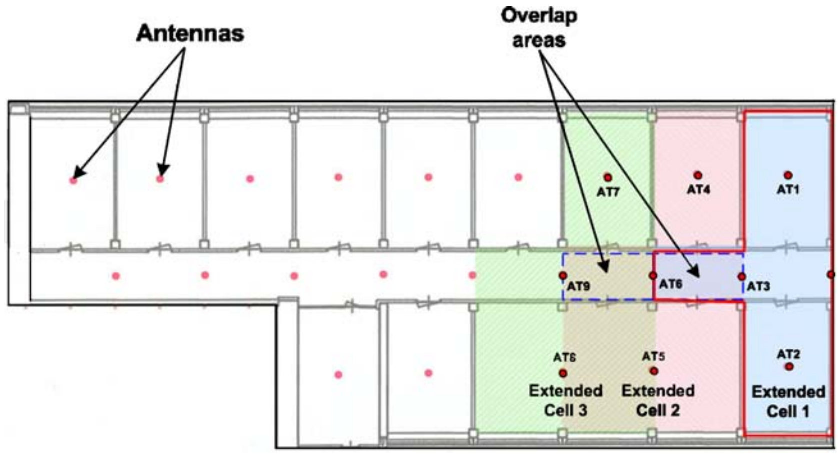

Fig. 7 The extended cell (*EC*) concept

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 m). 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 [12, 18]. 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. 7). 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 [12]. The simulation results in Fig. 8 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 trade-off 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 4.1. 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.

5.3 Self-configuration

Self-configuration refers to a means of automatically setting up networking-capable devices and organizing them in a network in the way that the intended tasks requested by users are optimally performed. For home networks, self-configuration is of great importance, as the network owners are most likely to have little or none expertise of network administration. It is also realistic to assume that they are not willing to have a third party administration.

Another important drive for seeking a sophisticated self-configuration strategy in home networks is fuelled from the

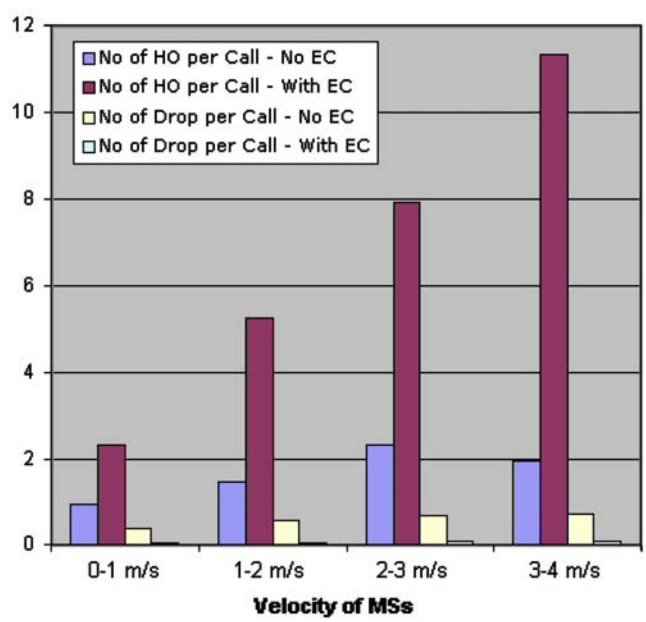

Fig. 8 Average number of HOs and call drops

characteristics of 60-GHz radio. While offering a great opportunity to prosper versatile bandwidth-demanding home applications, it raises greater challenges to realize a self-configurable home networking. The short radio range characteristics and the vulnerability for line-of-sight (LOS) obstruction of 60-GHz links result in frequent changing on link quality and network topology. This situation causes a large amount of reconfiguration processes. As the 60-GHz 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., IP configuration, service discovery, etc.) have great generality for all the radio technologies, the novelty of 60-GHz 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 reestablish 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 60-GHz radio with respect to the use of directional antenna, LOS links, and 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 [19] and are seeking a promising way to cooperate different levels of configuration under a cross-layer optimization strategy in the sense that the configuration information at different levels may be mutually beneficial. For example, it could be feasible and desirable to take into account 60-GHz channel state information available at the physical layer when making decisions at higher layer levels concerning channel allocation, cell formation, route selection, etc. However, as pointed out in [20], 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 while 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 form a centralized management structure. For the ad-hoc-based approach, besides the HCC, other capable devices should also be implemented fully or partially in the module to provide distributed management. In this way, hierarchical self-configuration management can be organized.

5.4 Cognitive networking

As the deployment of 60 GHz results in more dynamic and distributed networking environment, control and management of such a network stringently require the efficiency of the processes. That means that on one hand, the timeliness is highly desired for configure and adapt the 60-GHz 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 reconfiguration and adaptation processes must be decided on occurrence of the networking state changes, in other words, whether and when a reconfiguration 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 [21], 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 the reactive to the proactive manner. More specifically, the experience can help, for example, to predict ahead of time when a reconfiguration/adaptation needs to start. The idea is based on the observation that in-home usage of the network resource exhibits predictable 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.

Inspired by the idea of constructing a knowledge plane for the Internet [22], the architecture of the cognitive home network is expected to be implemented with a cognitive plane (CP). In our opinion, the CP is best to be positioned vertically crossing all the other three existing planes (i.e., data, control, and management planes) as shown in Fig. 9.

The purpose of this design is twofold. One is to enable 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.

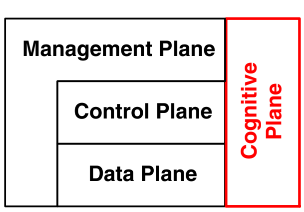

Fig. 9 FHN architecture: a view of plane division

A key question is how to identify the most applicable cognitive techniques for specific network control and management operations. 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 context should be consisted of. We can build here on the researches that have been done in context-aware computing and networking [23] and in ambient intelligence domain [24]. Although the concept of cognitive networking has illuminated a potential 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 [21], the prices of anarchy, ignorance, and control can be considered as further evaluation of the necessity and the fitness of adopting cognitive approach as the solution for the complex network problems.

6 Conclusion

In this paper, we review and present the main aspects of the 60-GHz radio regarding future home networks. We demonstrated two approaches to create a future-proof home network utilizing the 60-GHz band. The cell-based approach connects the rooms with fiber-optic cables and transmits the data at 60 GHz over these cables using the radio-over-fiber technique. The ad-hoc-based approach deploys special Via devices to enable the penetration of 60-GHz signals through the walls by forming a full wireless network all over the house. 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.

As the future work, we will keep working on the integration of 60-GHz technology into the home networks.

We will explore the challenges in more detail towards finding concrete solutions.

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