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Solving the uncertainty of vertical handovers in multi-radio home networks ☆

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ABSTRACT

In this paper, we investigate Decision Theory (DT) and Markov Decision Process (MDP) based approaches for vertical handover decision making in in-home networks. Here, we consider a heterogeneous network environment with both legacy WLAN and novel line-of-sight (LOS)-dependent 60 GHz radio systems deployed in home to support high quality multimedia applications. Both the above decision-making approaches take into account multiple subjective and objective factors, such as user preference, network condition, device capability and impact of the environment. We make decisions based on an evaluation of the candidate actions, but with different length of horizon. We show their ability to effectively make decisions, to handover or not, in uncertain situations. The method and results herein are in general applicable to any other situation where such a decision has to be made.

1. Introduction

The proliferation of radio technologies is paving the way for supporting a variety of in-home applications with an increasing demand for sustainable high data rates in the near future. To support high quality multimedia streaming, e.g., HDTV broadcasting, the attention of the research community has been on the higher frequency bands. As advocated by Smulders [1], a promising solution is the license-free 60 GHz band where bandwidth is abundant, and the data rates of the order of 1 Gigabit per second are easily feasible. 60 GHz radio is intended to provide connections for very high data rates within a short distance, mainly in the in-door environment. To save transmission power while ensuring satisfactory link quality at high data rates, a directional antenna configuration is recommended for the system to counteract the severe attenuation and to combat multi-path effects [2]. Therefore, line-of-sight (LOS) propagation has been one of the requirements for 60 GHz radio. However, LOS propagation cannot be guaranteed, especially in the in-door environment with many potential obstructions due to human activities and other objects in the surroundings. Experimental results in [16] show that a mean attenuation value of 22 dB is observed when a person obstructs the 60 GHz LOS link.

The trend in the in-home networking is that the network is more heterogeneous and supports multiple radio systems. The problem due to vulnerable 60 GHz LOS transmission can thus be resolved by a vertical handover of a communication session from one radio to another to maintain the continuity of the session. Fig. 1 gives an example, where both a 60 GHz radio cell and a WLAN cell are formed with a single access point, and are overlapping inside the house by using Radio-over-Fibre (RoF) technology [3]. For multimedia content distribution, streaming via a 60 GHz LOS link is always a preferable option as it is able to achieve the high data rate that is enough for the media content with high resolution. Thus it can offer the users a better perceptible service quality. If the LOS link is lost, a strong degradation of the perceived quality is very likely due to the disruption of the session. However, the LOS blocking is often a temporary phenomenon lasting for a short period. Nonetheless on a few occasions it can last for many seconds or even longer. Therefore, it is necessary to perform handover in some cases, whereas we just need to wait for the end of blocking in other cases. Switching back and forth will cause additional cost (power, display pause, etc.). Thus it is critical for the system to make a decision in time to handover. In fact, whenever the LOS link is lost a decision has to be made – whether to switch to the backup WLAN for streaming multimedia content under reduced quality, or to wait without switching hoping that this disturbance is just a transient effect. If the LOS link recovers rapidly with a possible short blocking duration then "*waiting*" action avoids unnecessary switching. However, if the outage of the link is longer, then "*switching*" action may avoid session break down. Thus the goal is to minimize perceptible quality degradation and make a well informed decision to switch between the available radios.

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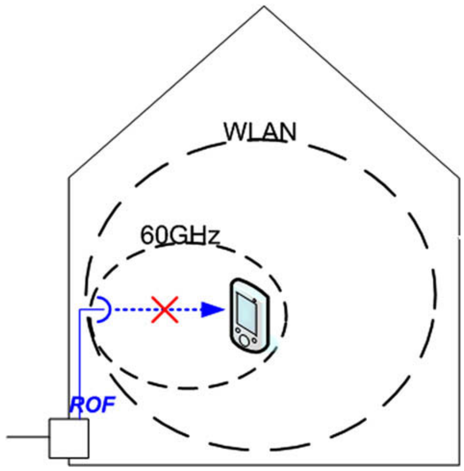

Fig. 1. Indoor radio links.

The main focus of this work is to device methods to tackle and study this problem.

In this work, we designed and examined two decision algorithms to solve this uncertainty of vertical handovers in 60 GHz radio system as shown in Fig. 1. The first algorithm is based on the decision theory (DT), where the handover decision is modeled as an episodic decision problem and actions are evaluated using the outcome of the current state. The second algorithm uses Markov Decision Process (MDP), where the decision problem is considered to be sequential. It is different from the decision theory approach where the decision depends not only on the outcome of the current state but also on the states that evolve afterwards. Both the algorithms are able to take into account multiple factors to make decisions in uncertain situations based on an evaluation of the candidate actions, but with different time horizon. Without loss of generality, both methods are potentially applicable when a decision has to be made amongst available multiple radio systems when the link quality of the current radio deteriorates significantly. Further, this type of uncertainty can be seen in many other situations such as selecting a route in a network with frequently failing paths. Thus we believe that this study can be altered to suit various such situations with slight modifications.

The rest of the paper is organized as follows. Section 2 provides a brief survey of the earlier studies for vertical handover decision. Section 3 gives an overview of the system model. In Sections 4 and 5, the vertical handover decision-making task is modeled with the Decision Theory and Markov Decision Process, respectively. Section 6 shows the detailed simulation setup, results and discussions. In the end, in Section 7 we conclude this work and discuss the future enhancements.

2. Related studies

Traditionally, vertical handover decisions are simply made based on comparing different radio systems in terms of link and network level performance indicators, such as, the received signal strength and throughput. de Sousa et al. [4], examined four algorithms – load balancing algorithm, coverage threshold algorithm, rate maximizing algorithm and theoretical circuit switched equivalent algorithm. They show through simulations that by including further information such as location of the users, the handover performance could be greatly improved. Recently, more sophisticated decision algorithms largely based on Artificial Intelligence (AI) techniques are getting prominence. AI techniques are used to exploit relevant factors from networks and devices to better the vertical handover strategies. A vertical handover algorithm based on fuzzy control theory [5] considers multiple criteria such as information about the load, velocity of mobile terminal and a set of rules defined from *a priori* knowledge. Following similar principle, a decision algorithm has been proposed in [6] taking into account power levels of received signals, cost of operation of a particular network and the amount of unused bandwidth. In [8] vertical handover problem is formulated as a Markov decision process, where link reward and signaling cost functions are introduced to evaluate actions. However, the reward is measured based on the bandwidth and connection delay, and thus the decision is insulated from the user's perceived experience of the service. Perceived quality of service, nonetheless, is of great importance for emerging user-centric networking paradigm [9]. In [7] a context-aware decision algorithm based on Analytic Hierarchy Process (AHP) is designed considering both static and dynamic context of the user, characteristics of terminals and the network. The networks are ranked with great consideration of the users' preference before the mobile terminal executes a handover. However, the ranking algorithm lacks sophistication and is formulated in a rather simplistic manner with coarse granularity.

It has always been a challenge for networks and/or mobile terminals to solve the issue as described in our example shown in Fig. 1. On one hand, the dynamic and random nature of occurrences of blocking events bring high uncertainty into the handover decision making; on the other hand, the decision should be made under substantial influence of multiple subjective and objective factors such as user preferences, network conditions, device capabilities and environmental impact. This kind of uncertain and complex situations is thus fuelling the need for sophisticated networking approaches and decision algorithms. This paper attempts to tackle this problem in networks where 60 GHz and WLAN are present; and in general, networks with multiple radios.

3. System model

3.1. Users' input

User preferences describe the users' experience of playing multimedia content which is delivered by the network with different radio systems. It is typically represented as discrete values or scores similar to ITU-T's Mean Opinion Score (MOS) [10]. The scores are usually found according to the rankings given by the users to quantitatively indicate their preferences on one radio system over the other. In this work, we use the so-called *utility* or *reward* to quantify the user experience when media stream is delivered through different radios. The density of this quantity, u, is defined as the subjective mean opinion score in each time unit as,

$$u = \begin{cases} u_{60}, & \text{streaming through 60 GHz radio system,} \\ u_w, & \text{streaming through WLAN system,} \\ u_z, & \text{connecting to neither system,} \\ & \text{ceased streaming and display.} \end{cases}$$

Qualitatively, it is easy to see that $u_{60} > u_w > u_z$.

3.2. The environment

The environmental impact is the occurrence of the blocking events for the sessions. It can be stochastically modeled by taking the duration of blocking and the interval between two blocking events. We model these events using expectation of blocking duration $E(t_{blk})$ and expectation of the duration between two successive blocking events $E(t_{nblk})$. With a model it would be easy to acquire some important collective characters of these randomly occurring events. It is also possible to predict the duration of blocking and