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A survey of QoS/QoE mechanisms in heterogeneous wireless networks

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ABSTRACT

Heterogeneous Wireless Networks (HWNs) are an important step in making connectivity ubiquitous and pervasive. Leveraging the increasing variety of connectivity options available to devices solves many problems such as capacity, spectrum efficiency, coverage and reliability. Anytime decisions are made for selection, handover, scheduling or routing many performance metrics along with energy efficiency and cost for access must be considered. The increased number of choices in an HWN makes the problem more difficult than traditional homogeneous networks since each Radio Access Technology (RAT) has unique characteristics. For instance, Bluetooth networks have low range and speed but are cheap compared to 4G networks. These types of observations can be factored into decision making in HWNs. Quality of Service and Experience should be considered so that the best possible configuration of connectivity, price and user application is made. All of this should occur autonomously. This paper provides a survey of recent works in HWNs with these ideas in mind. Existing approaches are categorized by function. Limitations and strengths of solutions are highlighted and comparisons between approaches are made to provide a starting point for further research in the area.

1. Introduction

Consumer devices such as mobile phones, laptops and tablets often include several options for connectivity. Most commonly, devices include: IEEE 802.11-based Wi-Fi, Bluetooth, and Mobile networks such as 3G, 4G or Long Term Evolution (LTE). Unfortunately, while there are many options available to connect, each of these particular Radio Access Technologies (RATs) was designed independently of one another, and interoperability was often not considered. With the exception of some basic mechanisms such as interference avoidance between RATs using Bluetooth and IEEE 802.11-based Wi-Fi, most RATs operate without any consideration of each other. In other words, RATs were designed to be homogeneous networks. Making use of multiple RATs to form a heterogeneous network, however, may introduce many desirable features to wireless networks. With more interfaces available, reliability improves since the network may failover to another RAT when one becomes congested or suffers from interference. Capacity may be improved if traffic is spread across different RATs, or across multiple interfaces [1]. The spectrum may be used more efficiently if channels which are idle become used more often when the load is balanced across RATs. However, it is a difficult choice to select a RAT, decide when to switch between RATs and route within HWNs. In modern networks, traffic has a variety of requirements based on the application. For instance, email and web-browsing are delay-tolerable compared with video streaming, VOIP or other multimedia applications.

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The aim of this paper is to break down the existing work into some of the main functions within an HWN and identify the strengths and weaknesses of all of the approaches within these areas. This analysis is performed with Quality of Service (QoS) and Quality of Experience (QoE) in mind. Open issues in HWNs are also discussed so that further contributions may be made. A QoS-aware approach tries to either split traffic up into priority classes (for example: high, medium and low), or tries to guarantee a particular metric value (for instance, delay under 30 ms) [2]. QoE on the other hand tries to combine more subjective aspects related to user perception into measuring network performance [3]. While there have been surveys performed in various areas in HWNs [4] and QoS [2], this categorization is unique and we highlight the strengths and weaknesses of the various approaches. This paper also includes several years of more modern references than some of the previous survey papers since HWNs have been a very active and fruitful area of research.

The main contributions of this paper are the following:

- A deep review of the state of the art of QoS/QoE in HWNs.
- Categorization of the mechanisms according to function.
- Comparison of the various techniques.
- Identification of areas for future work.

The rest of this paper is structured as follows: in Section 2, the motivation for this work is presented. The existing work in HWNs is then categorized by function. Handover and RAT/Access Point (AP) Selection are considered in Section 3. Medium Access Control and Scheduling in HWNs are discussed in Section 4. Topology and power control solutions are described in Section 5. Routing and HWNs are the topic of Section 6. At the end of each section, the surveyed papers are presented in a table which allows for easy comparison of the assumptions made by each approach and the limitations. This allows for easy identification of future directions of research. This also aids in assembling a suite of approaches for a complete set of protocols and architectures for a QoS/QoE focused HWN. Lastly, some brief conclusions and future directions are given in Section 7.

2. Motivation

Modern wireless devices contain multiple RATs which can be used to connect to each other and to the Internet. Traditionally each RAT was designed independently as a standalone technology, in other words—a homogeneous wireless network. For instance, Wi-Fi (802.11 a/b/g/n) WLAN technology is not designed to work with Bluetooth, Zigbee, 802.15 wireless personal area network (WPAN) technology (although in some cases there are mechanisms to avoid outright interference). While some standards have been draughted to address interoperability between non-compatible technologies, their focus is limited. Typically the focus has been on one RAT operating in the presence of another. For example, Bluetooth 2.1 and newer supports Adaptive Frequency Hopping (AFH) [5]. This avoids using the same frequency as Wi-Fi operating in the same location. Even though QoS/QoE is supported in the individual RATs, in many cases, solutions which have been designed for a particular RAT often do not translate well in networks which are made of heterogeneous technology.

QoS has been well studied in other areas of service provisioning, for instance, telephone networks [6] and telecommunications networks [7]. More recently it has also been applied to more related problems in wireless networking. In WLANs, QoS-based techniques have been applied successfully, particularly for provisioning resources [2]. However, these problems have the benefit of central co-ordination at the access point and a global view of all resources. The problem of matching users with an AP in an HWN is similar to that of multi-hop wireless networks. A global view becomes impossible, particularly as the network size grows. While most component networks within the HWN are likely to be a single hop, there is potential that the information will not be shared between operators. Each operator will likely need to make a decision on which users to admit independently. Compared to existing networks, users now may choose the operator they wish to connect to, and also the RAT. This further complicates the network selection problem for the users by giving them more choice and more metrics to consider.

The extra complication for users means that autonomy in HWNs is an important topic that should be kept in mind throughout this research. Many studies [8–10] show that networks are quickly becoming too large and complex to manage by human administrators alone. Further, it has also been shown that some of the greatest costs for Internet Service Providers (ISPs) are in managing and administrating networks. In many countries around the world, mobile ISPs especially are struggling to keep costs down and revenues high enough to maintain profitability. Autonomy is a key method which can mitigate some of these problems [11]. There are many key portions of the network that may be automated. The addition and removal of nodes should be automatic. This means the assignment of addresses, routing, and scheduling algorithms should all be able to deal with a non-static network topology. Specific technologies could be automatically detected and appropriate network mechanisms activated for handling the interactions between the networks. From the users' perspective, the HWN technology itself should be very automated and seamless. Once a user profile has been established with some basic parameters such as how much the user is willing to pay and what hardware/RATs are available, the network and the user device should be able to maintain connectivity anywhere there is HWN access.

3. Handover—RAT/AP selection

Handover is related to initial AP/RAT selection because it is an ongoing process while a user device is connected to the HWN. At any point in time, based on mobility or changing network conditions, it may be better for a device to switch its point of connection with the network. This problem is more difficult than simply selecting the best network because some emphasis must be placed on maintaining the connectivity to the network. If the device is too keen to make connection switches, the device may