# Supporting Mobile Devices with Wireless LAN/MAN in Large Controlled Environments

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## ABSTRACT

The functionality of mobile devices has grown exponentially in recent times. This has led to smart phones and the mobile Internet becoming a big success story. IEEE 802.11 wireless local area network, known as Wi-Fi, has become a standard feature on these devices and represents a viable alternative to using a mobile phone provider's network for connectivity. Users can surf the web, make VoIP calls, and more from their home WLAN networks or public hotspots. At present WLAN has too many outstanding issues to universally replace existing mobile phone networks. However, WLAN is ready to provide universal coverage for mobile devices in large controlled environments such as university and business campuses, sports stadia, and entertainment parks. In this article we outline the challenges in such a deployment and describe how the state of the art in WLAN can meet these challenges. Outstanding issues and areas requiring improvement are highlighted. With a view to overcoming these hurdles, some potential solutions and promising research directions are outlined.

## INTRODUCTION

The convergence of wireless communications, digital media, and information technologies on mobile devices has created an avalanche of exciting new applications and user experiences. Augmented reality is a great example of this technology convergence. Take the example of an augmented reality travel guide as seen in Fig. 1. This application uses the mobile device's GPS, digital compass, and accelerometer for location and orientation. Information on nearby points of interest is gathered from online sources via radio communications. The mobile device's camera and touch screen display are used to present the information overlaid on the camera view, creating an augmented reality.

The potential to design even more creative applications exists in large controlled environments such as entertainment parks, sports stadia, municipalities, universities, and business campuses. In the case of entertainment parks, they are often the size of a small city and just as populous. These parks already provide an exciting visitor experience, entertaining guests with an array of events, attractions, parades, concerts, exhibitions, and rides. Given the controlled nature of the environment, the potential for a mobile device to provide further interaction with the already interactive surroundings is compelling. A dedicated device could be provided to users on entry. The device would support new experiences in creative ways that are not possible with existing wireless devices such as the newest smart phones.

We have stated, and have seen with augmented reality, that the new wave of mobile applications require advanced wireless connectivity. A dedicated device as described above would also require connectivity throughout the entertainment park. In such a scenario, however, it would not be acceptable to have to pay a mobile phone provider for connectivity as for normal mobile devices. Alternatives to communication in the licensed spectrum used by mobile phone providers must be sought for the device.

Radio communication based on the well-known Wi-Fi standard IEEE 802.11 (wireless local area network [WLAN]) utilizes the unlicensed spectrum in the 2.4 GHz and 5 GHz frequency bands, allowing free wireless communication at high data rates. Free high-data-rate wireless communications using WLAN would allow the power of mobile applications to be harnessed on the device. For WLAN to work over a large controlled environment such as an entertainment park, it is necessary to have full coverage across the target environment as well as reliable communications, all at low cost and low complexity. Given the large crowds, reasonable data throughput for large numbers of devices in the same location would also be a requirement.

This article discusses the challenges in providing WLAN connectivity to mobile devices on a large mobile phone network scale. Although we are focusing on WLAN in the following, complementary standards for wireless metropolitan area networks (WMANs) exist and are not

*This work was supported in part by Enterprise Ireland's Innovation Partnership Programme and Disney Research.*

meant to be excluded in our discussion. Use cases that involve offering good quality to wireless-communication-based services within entertainment parks are discussed in the next section. These use cases are not restricted to entertainment parks and hence can be generalized to any large controlled environment. Where challenges are being met by the state of the art in WLAN, this is highlighted. Outstanding issues and areas requiring improvement are investigated. With a view to overcoming such hurdles, potential solutions and promising research directions are indicated.

## Large Controlled Environments: The Entertainment Park

When providing connectivity for large numbers of dedicated mobile devices, there will be unique challenges specific to distinct large controlled environments. The applications and requirements will vary for sports stadia, municipalities, business campuses, and so on. In this section we examine some of the unique characteristics and requirements of an entertainment park.

The largest entertainment parks compare with a big city in scale. The Walt Disney World Resort in Florida, for example, spans over 100 km$^2$, an area greater than that covered by the California state capital, Sacramento. With tens of thousands of employees and millions of visitors each year, such a resort is as densely populated as a city. The parallels do not stop there; entertainment parks include other city elements such as busy streets and roads, and mass transportation including buses, trains, and even water taxis. The reasons people visit entertainment parks, however, tend to be different from the reasons most people spend time in the city: mainly leisure as opposed to work.

One use of a dedicated mobile device for this environment is to make it available to park guests to enhance their visit. Many park patrons already carry electronic devices such as digital cameras, smart phones, and game consoles with them. Unofficial entertainment park related smart phone software applications already exist, including entertainment park guides and applications that offer information on attraction wait times. Entertainment park applications for the Nintendo DS have also been trialed. For example, a DS with a park guide/GPS add-on, using the existing WLAN capabilities of the DS, provides an interactive entertainment park guide with up-to-the-minute information on wait times.

It is not a huge leap to envision a dedicated device for guests providing a park guide with a range of information services kept up to date via wireless communications. If communications are free, there is no limit to the amount of communication-based applications the device can run. Potential applications include device-to-device messaging, video streaming, attraction interaction, and multiplayer gaming. This would suggest using a communications technology such as Wi-Fi/WLAN, which operates in the unlicensed spectrum.

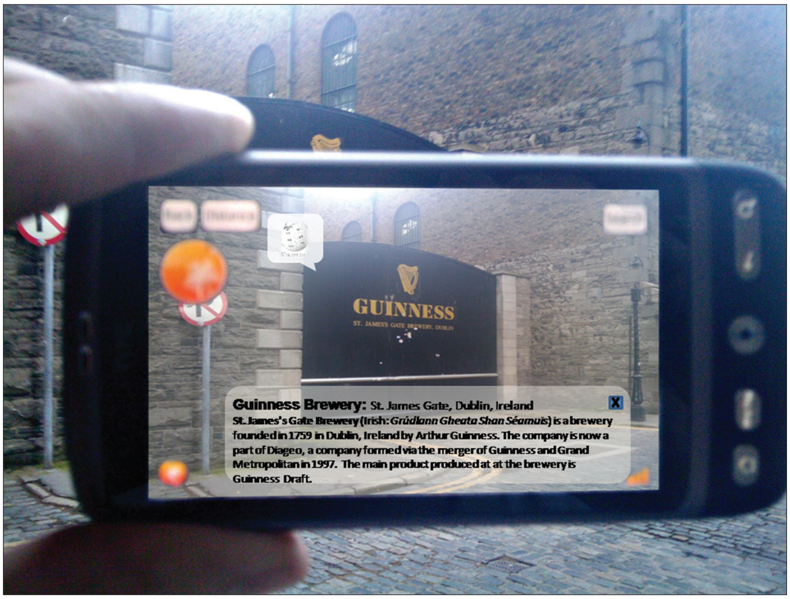


**Figure 1.** *An augmented reality travel guide for Dublin, Ireland.*

No assumptions should be made about users, as visitors to entertainment parks encompass every demographic. A single family group may contain elderly grandparents and young children. Thus, it is important that a dedicated device can be used intuitively by anyone. To aid ease of use, connectivity must be seamless and hidden from users in a similar fashion to that of a mobile phone. It would not be acceptable for a visitor to have to stop and search for a new wireless hotspot just because they have stepped off a street and into a building.

For each of the dedicated devices, but also for the overall system infrastructure, the required communication capacity and quality of service (QoS; e.g., throughput, delay) demands are application-dependent and difficult to predict. It is however reasonable to assume that demands will increase over time, when more and more sophisticated and useful applications will find their way onto the devices. It is therefore important to select a network and communication infrastructure that scales: it must be commercially feasible to incrementally increase system capacity by investing into the infrastructure where and when needed.

The entertainment park is clearly a challenging environment: there is a large coverage area; there are a large number of users, so the network must have high capacity; communications should be free, and visitors must be able to roam with seamless connectivity. Exact bandwidth requirements are hard to quantify for such a diverse environment, but a number of usage scenarios can be envisioned. Next, four specific scenarios encountered by the device within the environment are examined. The challenges they pose for wireless communications are explored.

### Scenario 1: Visitors Waiting in Line

A large number of visitors are waiting in line for a park ride. To entertain waiting guests, a multiplayer game is played. To do this, a waiting guest's dedicated device will interact with the

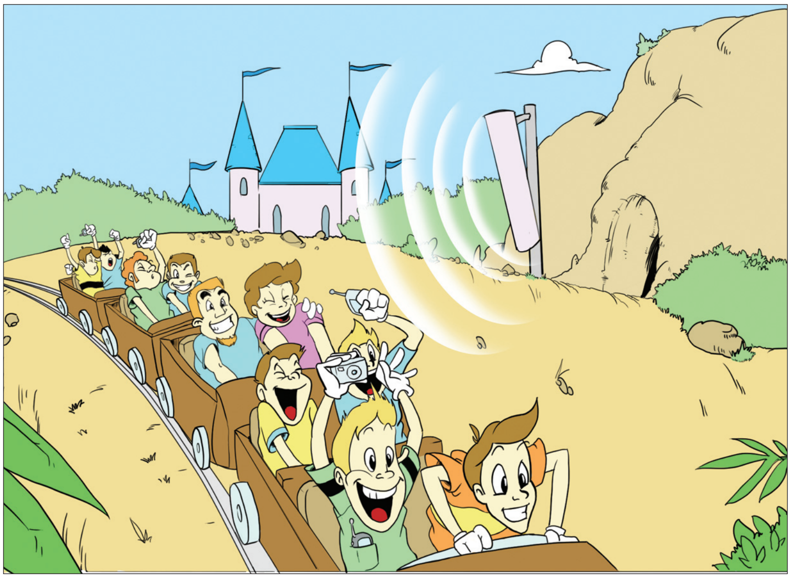

**Figure 2.** *Rides like rollercoasters and park transport move at speed.*

devices of nearby guests and a nearby interactive attraction such as a large screen. There are a number of interesting aspects from a communications perspective: there is a very high density of users, users move slowly but are in a constant state of flux (groups arriving and leaving the line), and the device is used for game control but not display (volumes of data exchanged are not large, but exchanges are frequent and time-sensitive).

#### SCENARIO 2: VISITORS ON A PARK RIDE

Visitors exchange data with park infrastructure to record stats while on a ride. During a ride visitors move at high speed (Fig. 2) and undergo rapid accelerations through a changing environment. Challenges include sharp bends, sudden changes of altitude, tunnels, and water hazards. The data volume is not the concern here, but rather supporting communications in the ride environment.

#### SCENARIO 3: STREET CROWD

Visitors on a crowded street are using the dedicated device for location-based applications such as a park guide with navigation. A Street Crowd scenario (Fig. 3) is characterized by an average density of users who are highly mobile (moving at walking speed). In this case the challenge is supporting interactive applications that exchange small amounts of data frequently but sometimes require support for more data-intensive services like video streaming.

#### SCENARIO 4: SEATED AUDIENCE

A seated audience is found in locations such as novelty restaurants, theatres, and similar arenas. Applications may include interactive menus for remote orders and audience participation during live shows (e.g., devices are used for voting in an *ask the audience* segment). In this scenario there are a number of important aspects from a communications standpoint: there is a very high density of users in a large area; these users are, however, stationary, but may be in an indoor location; and the volumes of data exchanged are small, but frequent and time-sensitive.

It is clear that the entertainment park environment poses even more challenges than first thought. Potential requirements include the ability to support communications at high speed, the need for very high capacity or a large number of closely coexisting access points (APs) to support dense crowds, and QoS support for delay-intolerant applications. The next section deals in greater detail with the technical challenges of deploying such a network. The elements of the WLAN standard that meet these challenges are also discussed.

## CHALLENGES IN LARGE WIRELESS LAN/MAN NETWORKS

There are a host of challenges involved in deploying a large WLAN/WMAN capable of supporting rich communication-based services on a large number of mobile devices. In this section we discuss those challenges from the top down.

In an infrastructure-based IEEE 802.11 deployment, a fixed wired station with expanded capabilities provides network connectivity to end user stations: this is an AP. To provide ubiquitous wireless connectivity across a large controlled environment such as an entertainment park, a dense deployment of IEEE 802.11 APs is needed. Just as in cellular networks, there must be a standardized method for the individual cells (AP sites) to coexist/combine so as to provide seamless connectivity to end users. The complexity of the network structure is hidden from end users, who see it as a single large network.

The IEEE 802.11s[1] draft standard amendment, which defines how wireless devices can interconnect to create a mesh network, is suited to this purpose. Wireless mesh networks have been widely deployed to provide ubiquitous coverage in municipalities worldwide. They are used to cover metropolitan areas, entire cities, and even whole counties. The biggest advantage of 802.11s is that it dramatically reduces the cost of network deployment. The prohibitive cost of network deployment is that of the wired infrastructure required to interconnect APs. 802.11s removes this barrier by allowing APs to interconnect wirelessly; however, there are a number of outstanding issues if the technology is to scale successfully.

For wireless devices to coexist in close proximity, they must communicate on orthogonal channels. Orthogonal channels are communication channels that reside in non-overlapping regions of the frequency spectrum. A typical WLAN channel occupies 20 MHz of the frequency spectrum. As illustrated in Fig. 4a, devices operating at the same frequency cause interference preventing communication, whereas devices operating on orthogonal channels can communicate without interference (Fig. 4b). The number of APs capable of coexisting per unit area will affect the scalability of a large wireless LAN/MAN network. Consequently, the availability of orthogonal channels affects the scalability of the network. The number of orthogonal

[1] *IEEE P802.11/D4.02: Mesh Networking (Draft Standard), Mar. 2010.*

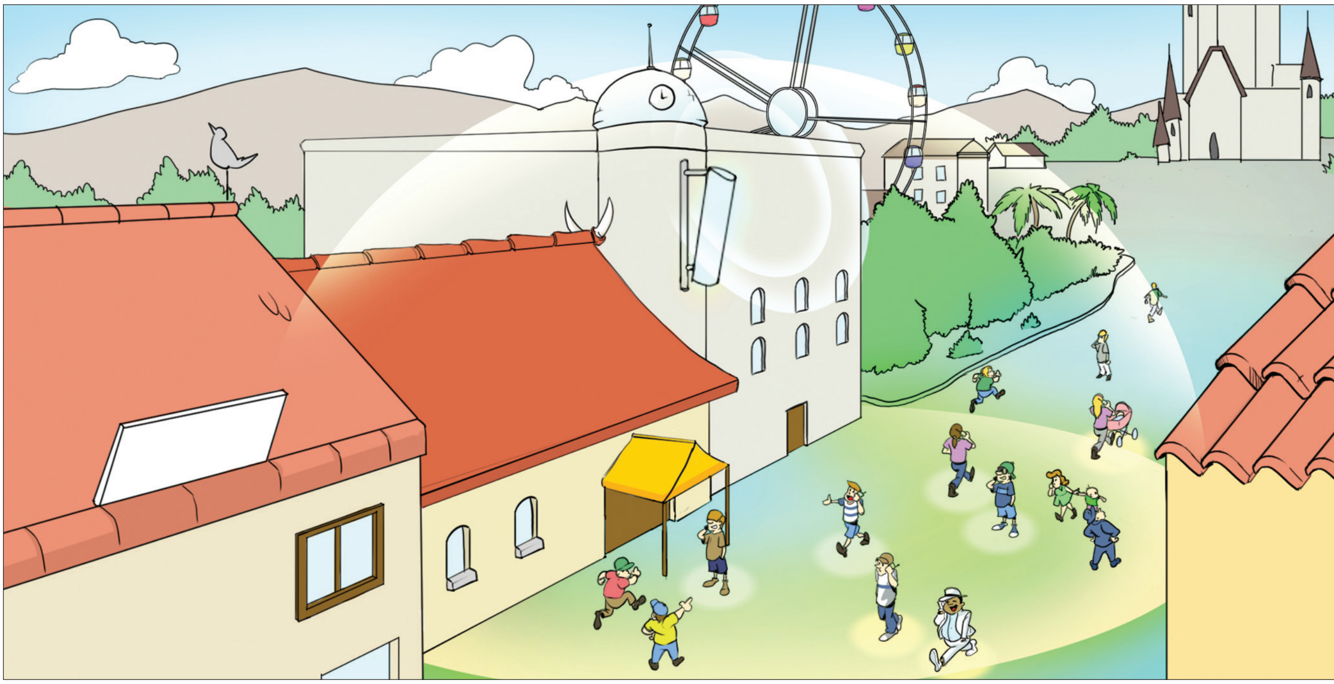

**Figure 3.** *Trying to provide connectivity on a busy entertainment park street.*

channels increases with the width of the region of frequency spectrum available for use.

The existing WLAN standards 802.11a [1] and 802.11g [1] operate in the 5 GHz and 2.4 GHz regions of the frequency spectrum. 802.11b [1] is not considered as it has been superseded by 802.11g. 802.11a typically offers 19 non-overlapping channels, while 802.11g offers just 3 non-overlapping channels. The 802.11y [2] amendment to the standard allows communication in the 3.6 GHz region; this mode of operation is, however, limited to the United States at present, and must also be licensed. In a deployment where the 22 channels offered by 802.11a and 802.11g are insufficient, additional spectrum usage must be considered; one potential solution is the use of TV white space.

In November 2008 the FCC opened up TV white space for use by unlicensed devices [3]. Four bands of frequency are allocated for broadcast television in what is known as the VHF and UHF regions of the radio spectrum (54–72 MHz, 76–88 MHz, 174–216 MHz, and 470–806 MHz). TV white spaces are regions of this spectrum that are not used locally. There are likely to be more of these TV white spaces as television makes the shift from analog to digital. An amendment to the standard has been proposed in order to take advantage of this newly available unlicensed spectrum, 802.11af.[2] By operating in this spectrum, it is expected that 802.11af can provide as many as 50 5-MHz channels. The number of new channels available varies in different geographical regions depending on local TV broadcast activities. Any additional capacity helps scale a wireless LAN/MAN to support rich communication-based services for a large number of end users.

As well as having sufficient orthogonal channels to scale, the network must allow users to move between AP sites without interruption. This type of mobility support is taken for granted on mobile phone networks and allows users to communicate while travelling at high speed in vehicles or trains. There are a number of standard amendments that are relevant when building support for mobility. The IEEE 802.11k [4] standard amendment provides for radio resource

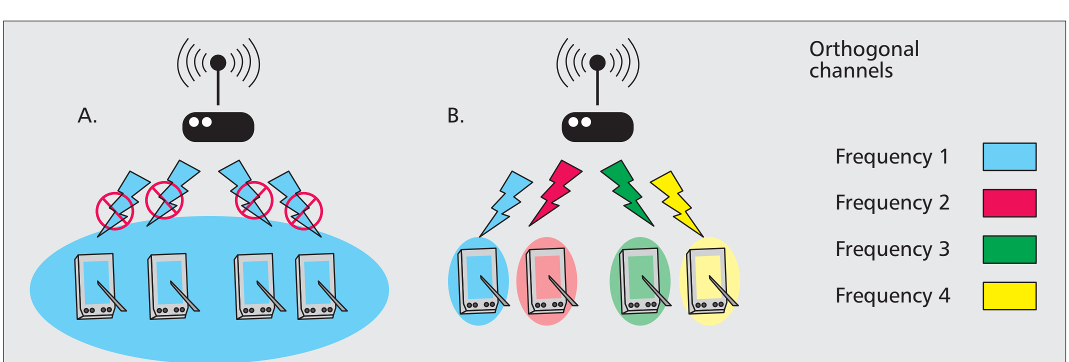


**Figure 4.** *Devices operating on orthogonal channels do not interfere.*

[2] *IEEE 802.11af: Wireless LAN in the TV White Space, 2010 (Proposed)*

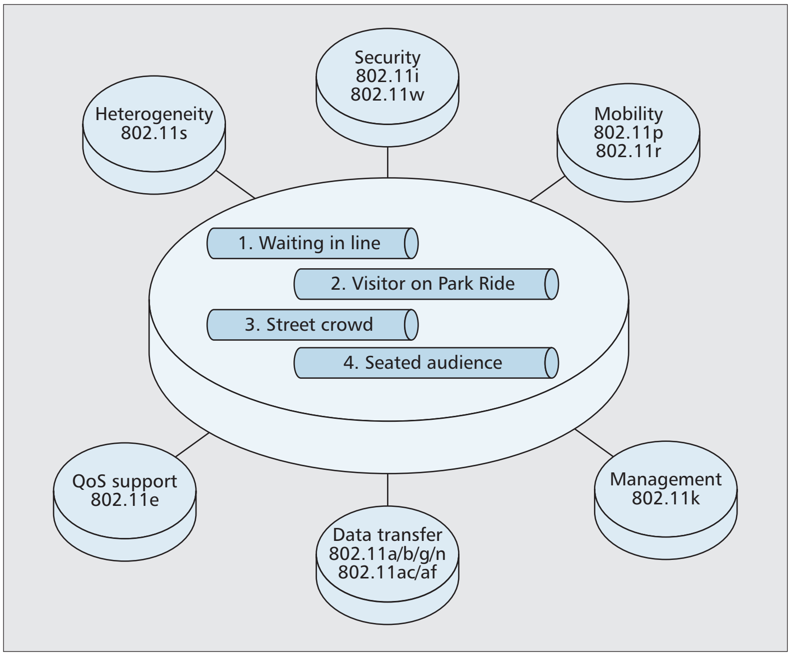


**Figure 5.** *IEEE 802.11 solutions mapped to the entertainment park scenario.*

measurement. This makes information based on measurements of the state of the radio environment available to the upper layers in the communications stack. Such information is useful when making decisions such as when to transition from one AP to another. The 802.11r [5] standard amendment allows for a fast transition between APs, and maintains both security and QoS.

Providing mobility support becomes more difficult as the end user's speed increases. Devices moving at speed create new challenges for the wireless network due to a rapidly changing radio environment and the short duration of communication times with AP sites. The 802.11p [6] draft amendment for wireless access in the vehicular environment (WAVE) addresses these issues by speeding up the mechanism for associating with APs, and improving the radio's immunity to the destructive effects of high speed by enhancing the standard at the physical layer. It may be necessary to use IEEE 802.11p in an environment like an entertainment park if connectivity is required while on high-speed rides or park transport.

Security across the network is another very important concern, especially in corporate environments where a denial of service attack could mean loss of revenue, and data theft may have serious implications. The early iterations of the WLAN standard had notoriously poor security mechanisms. The ease with which hackers could intercept transmissions and gain unauthorized access to wireless networks was well documented at the time. Since then the issue of security has been addressed with amendments to the standard. The 802.11i [1] enhanced security amendment brings 802.11 security up to date with government-strength encryption using the Advanced Encryption Standard (AES). For corporate-level security the encryption can be coupled with an authentication process. One means of providing authentication is to use a Remote Authentication Dial In User Service (RADIUS) authentication server with a suitable authentication method. Security was further enhanced by the 802.11w [7] protected management frames amendment. Prior to this amendment, management frames were unprotected, and systems could be disrupted by attacks impersonating valid equipment and disseminating false information. The 802.11w amendment closes this avenue of attack by properly securing management frames.

The individual AP sites are the basic building block of the network. The wireless capacity available at each of these will greatly influence scalability. IEEE 802.11a and 802.11g both offer an over-the-air throughput of 54 Mb/s resulting in an estimated maximum throughput of 25 Mb/s at the medium access control (MAC) service AP [8]. This means less than 25 devices can be supported with individual throughputs of 1 Mb/s as additional throughput is lost when separate devices contend for the medium. If the maximum throughput can be increased, the number of devices that can be supported at each AP site also increases. As data rates increase, individual users occupy less airtime on communication channels, which increases the capacity of the entire network. The 802.11n [9] amendment to the standard provides enhancement for higher throughputs. Using techniques such as multiple-input multiple-output (MIMO) and increasing channel width from 20 MHz to 40 MHz, over-the-air throughputs of up to 600 Mb/s are achievable with 802.11n. MIMO uses multiple antennas to transmit and receive more information than is possible with a single antenna. If existing standards cannot provide enough bandwidth, two working groups, 802.11ac,[3] Very High Throughput at less than 6 GHz, and 802.11ad,[4] Very High Throughput at 60 GHz, are promising to push WLAN throughput beyond the 1 Gb/s barrier. These developments will make possible new applications such as the wireless transmission of digital cinema [10], but may also allow a great many more mobile users to be supported at AP sites.

To support the next generation of digital media application, it is not simply enough to increase throughput; applications such as voice over IP (VoIP), video streaming, massively multiplayer online (MMO) games, and other communication-based rich media services have strict delay tolerances that must be serviced. Take, for example, video streaming; if delays become too great, the video playback becomes jittery or stilted and is unwatchable. To avoid the problem, applications of this nature require QoS guarantees. The WLAN standard provides support for QoS via the 802.11e [1] standard amendment. With 802.11e, traffic may be prioritized based on four categories: voice, video, best effort, and background. For QoS to be successfully implemented on the wireless network, it must be backed up by support for QoS on any associated wired network through the IEEE 802.1p *Class of Service* field provided by the 802.1Q [11] virtual bridged local area networks amendment to the Ethernet standard.

In Fig. 5 we can see all the IEEE 802.11 solu-

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*[3] IEEE 802.11ac: Very High Throughput <6 GHz, 2010 (Proposed)*

*[4] IEEE 802.11ad: Very High Throughput 60 GHz, 2010 (Proposed)*

tions discussed mapped to the entertainment park scenario. IEEE 802.11i and w provide the security needed for this type of corporate environment. IEEE 802.11p can support the kind of mobility found on park rides and transportation. It can be seen that many of the challenges in deploying a wireless LAN/MAN to serve a large numbers of end users are being met by existing elements of the 802.11 standard. Further challenges are being tackled by draft and proposed amendments to the standard, there are still outstanding problems, however. These issues and potential solutions are discussed in the next section.

## OUTSTANDING PROBLEMS AND APPROACHES TO IMPROVE PERFORMANCE

There are many obstacles to overcome in a WLAN/WMAN deployment that supports communications for a dedicated mobile device in a large controlled environment. This section is not intended to be an exhaustive list of these issues but rather a cross section of the wide variety of areas where problems may be encountered. Potential solutions in today's research are discussed where appropriate.

When installing a WLAN/WMAN infrastructure to cover a large area, IEEE 802.11s wireless mesh has a number of distinct advantages. By replacing wired links with wireless, the installation cost is reduced. The dynamically self-organizing and self-configuring nature of mesh networks also further reduces the complexity and cost of installation, and makes the network robust to the failure of single AP sites. There are, however, some problems with mesh networks. A large number of APs must coexist across a target environment in order for a wireless LAN/MAN infrastructure network to scale. In a wireless mesh wireless links that are in range of each other on a multihop route cannot be active on the same frequency at the same time, or interference occurs. This must be solved by either scheduling or multifrequency approaches. Scheduling introduces delays, which seriously hamper scalability, so multifrequency approaches are preferable.

Wireless devices can coexist by operating on orthogonal channels. For this to work in a wireless mesh network, network nodes must be able to operate at multiple frequencies rather than just one single fixed frequency. One approach taken is to use a single radio capable of operating on different channels, but only one at a time at each network node. It is also possible to use a single radio with multiple transceivers controlled by the same MAC mechanism to allow operation at several channels simultaneously. Maximum flexibility is achieved by using multiple radios. These radios can operate independently, and, in theory, each could be capable of operating on multiple channels. The three approaches listed progressively increase complexity, but also provide additional capacity. The benefit of these multifrequency approaches is a reduction in interference and latency in mesh networks. This is achieved through greater flexibility in channel allocation, allowing nearby nodes to coexist on orthogonal channels, thereby increasing network capacity. Multifrequency approaches, however, increase complexity and pose some additional problems, especially for smaller handheld devices.

The size of a mobile device is a major limiting factor to what is possible. A handheld device has limited battery life. Radios are one of the most power-hungry pieces of hardware on such a device. This may threaten capacity-enhancing approaches that propose multiple radios. Some multiple-radio approaches are, however, designed to improve battery life. For example, a low-power radio can be used in conjunction with a high-power radio. The high-power device is shut down when idle, and the low-power radio monitors whether data is available, waking up the high-power radio when needed. Another factor working against multiple-radio or multiple-antenna solutions (e.g., IEEE 802.11n MIMO) is antenna placement; it is difficult to place multiple antennas in a handheld device without experiencing crosstalk or other forms of interference. Even the proximity of the user's hand must be considered, as an antenna obscuring hand may be a major source of interference. On modern devices with sophisticated displays that allow multiple orientations (Fig. 6), hand position can be a real issue for wireless communication; for example, Apple's iPhone 4 had a high profile problem with antenna placement that led to lost connections when the lower left side of the device was touched.

*Some multiple radio approaches are designed to improve battery life. For example, a low power radio can be used in conjunction with a high power radio. The high powered device is shut down when idle and the low powered radio monitors whether data is available, waking up the high power radio when needed.*

There are a number of potential development platforms for a custom dedicated mobile device, and the choice of operating system is an important design consideration. Competing mobile operating systems include Symbian, Maemo, MeeGo, iPhone, BlackBerry, and Android. If, for example, the Android operating system and software stack is to be used, as with any of the other operating systems, there are benefits and drawbacks to consider. This platform is based on the Linux kernel, which is free and open source and, consequently, appealing to the research community. There are many benefits for developers too; if you wish to develop with a new piece of hardware, provided it has a Linux driver, porting to Android is a relatively simple procedure. At present, however, the platform has a problem working with WLAN networks: it is not possible to set up proxy settings for a WLAN network (a documented bug since November 2008). This lack of proxy support is a major concern, especially for corporate networks.

Proxy servers are used by corporations and institutions such as universities to improve security and enforce policies and restrictions (e.g., preventing access to sites unsuitable for the workplace). One way of overcoming this Android problem now is to create a custom build of the OS with proxy restrictions removed for WLAN, and then build a proxy setting App. The custom build of the OS and the proxy App can then be distributed to all devices. This way of overcoming the problem is not ideal, as it increases platform fragmentation and complicates interoperability. Ideally, proxy setting functional-


**Figure 6.** *Hands cover different areas depending on device orientation.*

ity would be included in the standard Android OS in a more intuitive fashion (e.g., a configurable parameter associated with known wireless networks).

Many upper-layer protocols required to support applications on mobile devices were originally designed for wired networks. Unfortunately, some of these do not perform well in wireless networks. For example, transport layer protocols, including the popular TCP protocol, were developed for wired networks. Wireless links, especially in the presence of mobility or ad hoc wireless networks, behave very differently from wired links (in terms of packet loss and delay), and this invokes an inefficient reaction from the transport protocol. Congestion control mechanisms may treat the packet loss generated by the error-prone wireless channels as network congestion, and wrongly reduce their transmission rate. Similarly, an unreliable link in awireless ad hoc network may cause a packet retransmission over the entire path. This is highly inefficient, in terms of both delay and energy consumption. Several link-layer solutions that aid higher-layer protocols (mainly TCP) to cope better with link-layer QoS characteristics have been proposed. Such enhancements include Snoop TCP [12] and SPLADE [13], the latter being designed for real-time multimedia applications, which use buffering and local retransmission techniques to shield the TCP layer from the wireless QoS variations.

Newly developed upper-layer protocols designed specifically for wireless networks provide the solution to this problem and will very likely take over in wireless communications. Recently developed transport protocols include Stream Control Transmission Protocol (SCTP) [14] and Datagram Congestion Control Protocol (DCCP) [15], both of which support multihoming, a very important feature in the context of mobility and wireless heterogeneous networks. One proprietary solution is the Venturi Transport Protocol (VTP), which transparently replaces TCP to overcome its limitations over wireless networks. VTP is already used by a number of wireless broadband service providers to speed up their networks.

There are a wide range of issues to consider when developing a custom mobile device supported by WLAN infrastructure. We have highlighted some important considerations, including the limitations of the wireless network technology, restrictions of the device's OS, problems associated with upper-layer protocols, and even issues as simple as the space available on a hand held device.

## SUMMARY

This article focuses on the feasibility of using WLAN to support communication-based applications on mobile devices in a large controlled environment. An entertainment park is taken as an example environment, and the particular challenges for the entertainment park case are discussed. Existing WLAN standards, draft standards, and proposed standards that can meet these challenges are summarized. Finally, a broad cross-section of the remaining obstacles associated with such a deployment are discussed. Problems relating to infrastructure, operating systems, limited space on handheld devices, and upper-layer protocols are highlighted to show the scope of such an undertaking.

### ACKNOWLEDGMENTS

The authors wish to thank Kevin McGuinness for his valuable comments and contributions to this work. The authors also wish to thank Maurizio Nitti of Disney Research, Zurich for his help with illustrations.

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## BIOGRAPHIES

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