What is Cellular Communications: Mobile Technology

Mobile phone or cellular telecommunications technology has been in widespread use since the early 1980s.

Since its first introduction, its use has increased very rapidly to the extent that a major portion of the global population has access to the technology.

From developed nation to growing nation, mobile phone or cellular communications technology has been installed in all countries around the globe.

The cellular telecommunications industry has been a major driver in the growth of the radio and electronics industries.

Development of cellular communications

Although cellular communications are now accepted into everyday life, it took many years for their development to occur.

Although the basic concepts for cellular communications technology were proposed in the 1940s it was not until the mid-1980s that the radio technology and systems were deployed to enable widespread availability.

Usage of the cellular communications systems grew rapidly and as an example it was estimated that within the United Kingdom more calls were made using mobile phones than wired devices by 2011.

Another example of the growth of cellular telecommunications systems occurred in 2004 when the GSMA announced at Mobile World Congress in February 2004 that there were more than 1 billion GSM mobile subscribers – it had taken 12 years since the first network was launched. By comparison it had taken over 100 years for the same figure to be reached for wired telephone connections.

Then by 2015 more than 7 billion mobile subscriptions (for all technologies) were active. This is a major feat when it is realized that the global population was just over 7 billion. This meant that many people had more than one subscription, although market penetration was obviously very significant.

Cellular telecommunications generations

There is a lot of talk about the mobile phone generations. 3G moves on to 4G and then onto 5G.

Each mobile phone generation had its own aims and was able to provide different levels of functionality.

There may have also been several different competing standards within the different generations. For 3G cellular communications there were two main standards, but for 4G there was only one as there was global consensus on the system to use and this facilitated global roaming.

Smart Community Wireless Platforms: Costs, Benefits, Drawbacks, Risks

A smart city aims to embed digital technology across city functions including its economy, mobility, environment, people, living and, governance. Many cities have taken initiatives toward becoming a smart city to foster commercial and cultural development. A wireless network (e.g. Wi-Fi network) covering most of the city is a significant contributor and a major step toward becoming a smart city. Such a network offers many benefits in tackling challenges such as reducing traffic congestion, reducing crime, fostering regional economic growth, managing the effects of climate, and improving delivery of city services [1].

City-wide wireless networks are still desired even with the availability of cellular networks, mainly due to their low cost and higher bandwidth compared to cellular networks. Plus, people are more inclined to use the wireless networks where available as opposed to using their limited data plans. In addition to citizens, many smart IoT devices will require bandwidth and many of them will use protocols which are best supported by a city-wide wireless network.

One major issue with city-wide wireless network is the high cost of laying out the infrastructure, rolling out the services, allocating adequate bandwidth, maintaining the services. One question is who will setup the network and who will pay for it. A second question is who will supply the bandwidth while broadband bandwidth is still in shortage in most cities. Another question is who will pay for the supplied bandwidth.

What should the cities do? Should they rely solely on the wireless operators to build a wireless network across the city? In general, it is unreasonable to expect the private sector to setup a wireless network for smart city objectives. If not private sector alone, then how about some private-public partnerships? Despite numerous attempts in prior years, private-public partnerships and joint ventures between municipalities and private companies have failed to take hold. Furthermore, several states have enacted legislation to prevent municipalities from offering wireless services in many forms in the city for variety of reasons [2]. While there are so many failures in the past and there is political controversy, why should they still pursue a city-wide wireless network? Should they simply give up on their goals of being a smart city? How could they maintain their competitiveness without a wireless network in the digital age?

We think that cities could look for new approaches in realizing city-wide wireless network. One approach is to analyze the success of community wireless networks and try to find ways to leverage their success for building a city-wide wireless network. Indeed, there are many examples of successful community wireless network implementations [3, 4]. In this paper, we will bring attention to successes of community wireless networks and develop a model where municipality, communities and smart utility providers work together to create a platform, which we call smart community wireless platform, where different platform sides work together toward achieving smart community objectives. The purpose for this investigation is to take a new look at building a city-wide wireless network through a new model based on integrating smart community wireless networks over the span of the city. The objective of this paper is to present this platform and its various dynamics. Accordingly, the paper takes more of a conceptual approach rather than a technical one. The purpose is to introduce the smart community wireless platform. How such platforms could join to form a larger city-wide wireless network is a separate discussion we address in [5].

Smart community wireless platform

Earlier approaches involving municipality partnering with private commercial providers failed for variety of reasons [2, 6, 7]. We believe smart city starts with smart communities and hence the community involvement is significant in building a city-wide wireless network. We use the term smart to indicate the human factor in building and using the wireless network. Indeed, many community and neighborhood wireless models have been successful. The proposal is take it further through collaborations of communities, municipalities and other partners to realize a city-wide wireless network. In our approach, we will include the smart utility providers as a player in the platform. The question becomes: can communities, the municipality and smart utility providers work together to build a platform for the community? Let us first define the platform.

Platform definition

We will describe the platform by explaining its system architecture and by discussing its sponsor, its providers, sides, economic utilities and network externalities, financial resources and policies. We will outline the strategies for how to position, present, realize and operate it. For a general discussion of platforms and platform businesses,

A smart community wireless platform is a community wireless network built and maintained through collaboration of the community, the municipality and the smart service providers. There are multiple sides on this platform: (1) users who use the wireless network and they may also sponsor bandwidth, (2) bandwidth sponsors who sponsor bandwidth for this wireless network, particularly the businesses, (3) other smart service providers.

In this model, the community and municipality assume the main roles. The amount of involvement varies in realizations of this model in different cities and even within different communities in the same city. Municipality plays an important role in this platform in both supporting the communities and organizing them to participate into the city-wide bigger wireless network.

The users are community members or visitors that use the wireless network.

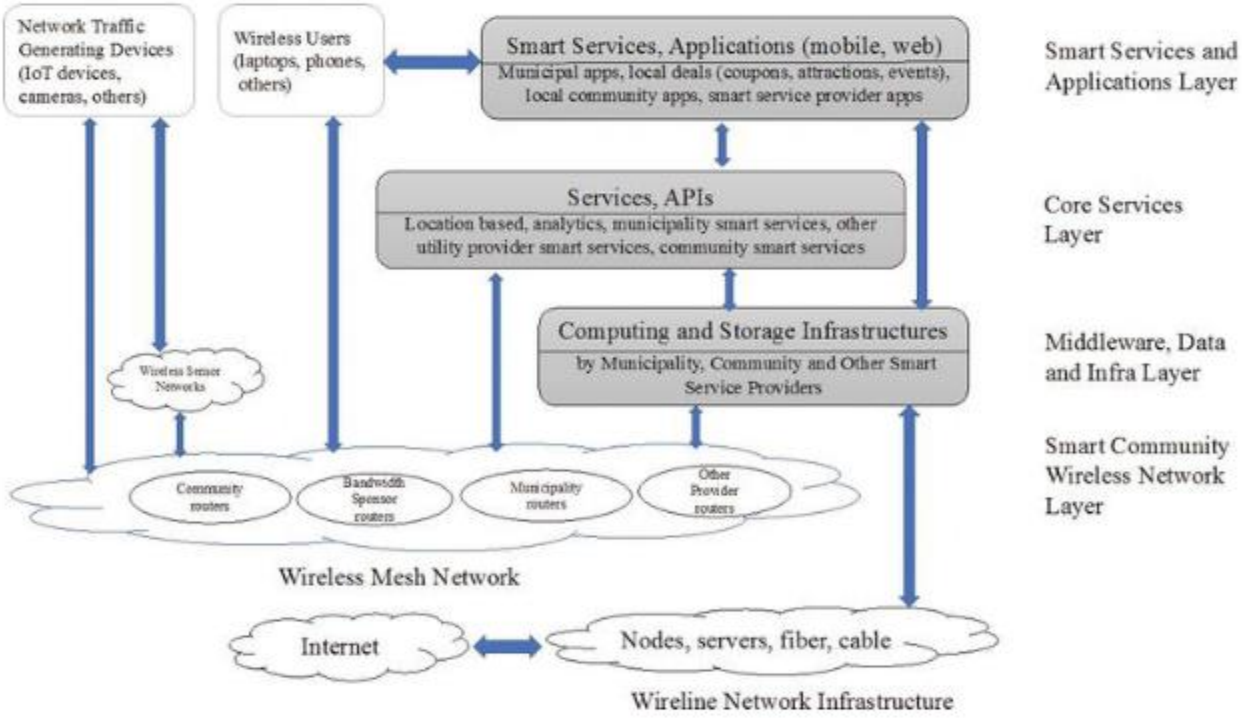
Bandwidth sponsors are entities that sponsor bandwidth used by the users to connect to the Internet. Community members may be users and bandwidth sponsors at the same time. Businesses, non-profits and organizations in the community become bandwidth sponsors. Smart service providers may become bandwidth sponsors. In this paper, we will focus more on businesses as the bandwidth sponsors that provide bandwidth for the users.

Smart service providers offer smart services to the users of the platform. One typical example is the utility provider companies like electricity, gas, water, waste management. For example, waste management company provides services for smart garbage collection to the users of the platform. We will not use the term utility for them (as in electricity, water, gas) in this paper as we will use the term utility to refer to economical utility for being on the platform. We will call them as smart service providers. These smart service providers use the community wireless network for communication of their smart devices (sensors, smart devices, and other IoT devices) that they place in the network. They benefit from the platform by placing IoT devices that use the wireless network for communication, or more likely by building sensor networks that integrate with the wireless network.

They sponsor bandwidth so they become bandwidth sponsors and they may provide other components into the platform as explained in later sections.

Another example to smart service providers is the city offices and department. For example, parks department provides services for park resources. Another example is the community itself in providing smart services to its members, for example, smart education services.

System architecture



Smart Community Wireless Network Layer: Wireless network is built on top of the wireline infrastructure that has network nodes, servers and cabling provided by community, municipality and smart service providers.

Middleware, Data and Infra Layer: Computing and storage infrastructures belonging to the community, municipality, and smart service providers in this system store data and offer computing, networking, caching and data storage resources. It contains software platforms and services including middleware, service oriented solutions, fog and cloud computing infrastructures (both commercial and community clouds). Other components include reliability, security, privacy and trust solutions. Infrastructure offered by smart service providers hosts the data and resources for smart services. Those infrastructures could be accessible through the wireless network. Given the complexity of the smart services and the extent of the data generated by the platform sides, this layer should be capable of storing and processing the data. It should be able to store and process various types of data including events, unstructured, structured, geo-spatial, crowdsourcing data. The smart service provider infrastructures may be required to perform real-time processing.

Core Services Layer: Some core services such as analytics, user location tracking, location-based services, search, semantics, context processing, visualization, collaboration platforms, geo-spatial services, access to public data and statistics, community social networking and other digital community services are offered using this infrastructure which is accessible by the wireless network. Outputs of data analytics and mining are offered at this layer. These core services are usually accessible to bandwidth sponsors and smart service providers.

Smart Services and Applications Layer: This layer includes all smart services offered by the smart service providers such as smart transportation, smart health and smart government services. This layer offers APIs of the smart services for application builders. Additionally, it includes mobile and web user applications offered by municipality, community and smart service providers.

Wireless users and IoT devices use the wireless network and generate network traffic. IoT devices belong to the smart service providers that participate in this platform. They are usually part of wireless sensor networks but can be directly connected to the community wireless networks. Network traffic from some of the IoT devices would not leave to the Internet, but rather stored, processed and analyzed in the infrastructure accessible by the community wireless network.

With this architecture, various services can be offered in a modern smart community. All these services are provided by smart service providers (e.g. private companies, municipal offices and communities). The platform creates an ecosystem around this system architecture. This architecture hosts an internet of everything environment including connected devices, users, communities offering community services, smart service providers using the network and offering their smart services.

The smart service providers are vertically integrated to provide their services over the platform. Some of these services are available only on this platform. The providers use the wireless network for collecting data from field devices into their infrastructures and may offer the same services over the Internet, which can be accessed by anyone. In any case, the wireless platform provides a home for the devices and for collecting their data. The providers contribute to this network by supplying access point routers that connect their devices to the wireless network and preferably by sponsoring additional bandwidth.

Internet access is supplied by bandwidth sponsors and commercial ISP services.

We will not present a detailed design of the wireless network in this paper, rather we will state our assumption. We assume the platform uses a mesh Wi-Fi technology as it is most often the technology used in such networks. In the network, there are access points and routers supplied by the community usually having generic server hardware and running open source firmware and software. The mesh network usually runs open source mesh network routing software and open source network management software to setup and manage a softwaredefined wireless mesh network. In addition to routers supplied by the community, there are routers supplied by the community members and other routers belonging to municipality, to the sponsors of bandwidth and to the smart service providers. The design should cover the whole target area by adding intermediary routers in places where no sponsor router is available and should be able to redirect user traffic to any of the available access points.

The platform relies on community members, businesses and organizations to share a portion of the total required bandwidth to access the Internet. So, a significant assumption is that ISPs allow plan sharing in their service terms. When bandwidth sharing does not supply the required bandwidth completely, remaining bandwidth needs to be purchased from the local commercial ISPs.

The mesh Wi-Fi network uses mechanisms for access control, metering and blocking the user traffic beyond a daily cap. It enforces rate limiting of the users with respect to data rate and the amount of download/upload. It employs self-adjusting network functionalities for fairness such as enforcing dynamic rate limiting the bandwidth to each wireless interface based on the current total number of users. When the number of users exceeds the network capacity based on minimum bandwidth for each device, new connection requests are not granted thanks to dynamic connection admission control. Therefore, some users will be blocked and not able to join. The city officials and municipal services have guaranteed service for accessing the wireless network, and they are not blocked.

The wireless network should offer enough bandwidth to fulfill the basic requirements of the users and support applications that will benefit the community and the city. Such applications include community social networking, community calendar of events and information about events, services offered by community, municipality and commercial smart service provider’s offer. On the other hand, it should not be positioned as a competitor to commercial cellular or wireless networks as we argue in Strategies For Platform Promotion and Positioning section. For example, it should not allow unlimited upload and download. One option is to rate limit the download/upload speeds. Another option is to limit the traffic to and from the Internet while the users could enjoy unlimited access to the smart services. In other words, their Internet traffic is metered and capped, however, traffic within the wireless network could be unlimited, or limited with a higher cap subject to the whole capacity of the wireless network.

The wireless network implements typical security and access control mechanisms .

When similar networks are integrated together, a seamless network covering a bigger span of the city could be possible .

Platform control

For the platform, it makes sense for the community to be the platform sponsor and the primary provider. Community has the say on management and policies of the network. The community decides on what policies and what strategies to apply. In another arrangement model, municipality and community may behave as the platform sponsors, but we will assume the community is the main sponsor and provider of this platform in this paper.

We assume no commercial offerings using this platform by municipality due to existing state laws. We assume the community does not engage in seeking any profit using the platform. The platform is not commercial and is not for profit for the community. For this reason, many of the concerns applicable to commercial platforms do not apply, like pricing but some other concerns apply like funding. We assume the platform will be free for users but possibly with some volunteering or sponsoring bandwidth in return, or with agreeing the usage terms and giving up some privacy.

The term sponsor is used in two meanings in this paper and they should not be confused: one in the meaning of platform sponsor which is the entities that control the platform. The other one is the bandwidth sponsor, for example, businesses that provide bandwidth for the wireless users to connect to the Internet.

Community mainly supplies volunteers and bandwidth sponsors. Municipality helps by allowing the community to use city owned light posts, traffic lights and municipal buildings for attaching access points, and by allowing to use wireline infrastructure; assisting the grant writers with grant applications; providing access to GIS mapping data; assisting with network design; financial help by identifying grants and tax breaks for community networks. With community and municipality working together, businesses and other smart service providers would join the bandwagon increasing the network externalities and adding value for the platform, therefore making it a viable platform.

The openness of the community wireless network is controlled by the community. Normally, the platform is open to any user provided they accept the usage policies. The community will decide on the criteria for who can join as developer and providers of services and on what conditions. The community decides whether the wireless network and infrastructures are open to any developer to develop some service/application, or to any smart service provider to install devices and provide services. The community will decide if research tools can be deployed by universities, or by local startup companies. The community controls the quality of the wireless network and the services offered on it. The community decides and governs what complements such as location tracking and analytics can be provided and by whom. The community makes these decisions following their decision making methodology, for example, may perform SWOT analysis for the complement providers and smart service providers. The complement providers could be commercial ISPs to sell bandwidth, other providers of the equipment, software, services and know-how.

Utilities and network effects

Each side of the platform has an intrinsic utility for being on the platform. For example, users have utility with being on this platform in the form of getting wireless service and additionally by receiving coupons, deals and other location-based offers, and accessing smart services. Businesses have utility for promoting and advertising their businesses. Similarly for the municipality and other smart service providers.

In addition to the intrinsic utility, each side experiences additional utility due to network externalities. Network effects exist impacting the utility of different sides for being on this platform. It is assumed that the user utility and network size would follow a logistic (“S”-shaped) function. Same side effects will help increase the user population thanks to information diffusion initially. Increase in population would later negatively impact the utility due to congestion, possible degradation in the quality of the wireless network and being blocked in the shortage of available bandwidth.

Cross side network effects exist. There could be positive network externality between users and bandwidth sponsors. Similarly between users and smart service providers. Policies and strategies would increase the network effects and thereby the utility of different sides. We will discuss some policies and strategies for taking advantage of the network externalities in subsequent sections. Network effects are so many and will be outlined in later sections.

Platform evolution

The community should exercise policies that will allow users, community members, component providers to offer ideas and contributions. The platform evolves by being open to community needs, fostering innovation by allowing community startups and pilot projects and university research and being a testbed for innovation. The use of open source supports such collaboration between global developers and the community developers. Collaboration among communities and tracking what other communities do will help evolve the platform into new technologies and approaches. The community should be transparent to the users about the evolution of the platform as to provide more accurate information about the future roadmap and shape the user expectations accordingly.

The community needs to monitor the total payoff and estimate the lifetime customer value (LCV) and a new user’s impact on existing users’ utility. Based on these, the community should find the optimum number of users the wireless network should support before considering investment for updates, upgrades and expansions. Therefore, there will be blocked users.

Financial resources

The smart community wireless platform reduces the financial responsibility for the city, but funding is still required. The municipality could continuously track and search for funding and try to maximize the amount of funding collected for the community platforms. For each grant, the municipality could maintain the area, the purpose, the conditions and constraints of the grant. Certain grants are given for specific applications and purposes (e.g. safety, energy, climate preparedness, transportation, health) and by different sources (e.g. by the Department of Homeland Security, Department of Transportation, Department of Energy, Department of Commerce, and the Environmental Protection Agency). Although many funding opportunities and sources exist, different communities may focus on different ones based on how the opportunities fit their needs and objectives. The community also should be on the look for funding sources by mobilizing its volunteers.

Funding sources include grants, tax benefits, donations (from local organizations, businesses, and community members), bandwidth sponsorships, new exploratory research funds, new hackathon challenges and awards, free services from companies (e.g. free cloud service), testbeds (for trials of different technologies, ideas, models), special funds (e.g. system and service for first responding by department of homeland security), and crowdfunding opportunities.

Policies

What should be the ownership, maintenance, and security policy for the platform? It is expected that the community owns the platform as being the sponsor. Regarding maintenance policy, it is expected the community maintains the network with the help of volunteers and part-time contractors.

Who should do the authentication and authorization of users? What should be the user privacy policies? For this platform, the community should control authentication and authorization policies. The users would have to give up on some of their privacy by entering their profile (e.g. via a survey at first login) and agreeing for being tracked for usage and for location. This information is used for analytics and improving the wireless experience, and is integrated into the loyalty programs and deals of the sponsoring businesses. The information is shared with the sponsoring businesses, which is an incentive to bring in more businesses and increasing their utilities. Additionally, this information is used to trace individuals in case of any illegal online activity on the network.

Strategies for increasing utility of platform sides

Strategies should be developed and employed to increase the value of the platform for different sides and to reach the critical mass in terms of regular users within the community and by visitors. These include strategies to mobilize the volunteers, officials, sponsors, non-profits, smart service providers, commercial ISPs, component and complement providers. There should be strategies in place for:

- Bringing in users by offering them a consistent service as well as access to business loyalty programs and smart services over the platform.
- Convincing private investment for upgrading the broadband infrastructure. Strategies for private investment to lay down more fiber, upgrade wireline infrastructure and services, improve wireless coverage and employ latest technology should be in place.
- Motivating city universities for research and development to help with technical and managerial initiatives. Provide them opportunity to test ideas, provide them with testbeds, nourish their business and management ideas.
- Bringing in other organizations (e.g. non-profits): they will not have much utility for offering their bandwidth just so that more people visit an economic district, but would have increased utility with contributing to the community in developing areas and for reducing digital divide.
- Bringing in smart service providers such as smart parking and waste management.
- Effective crowdsourcing and crowdfunding
- Convincing ISPs to allow sharing the broadband connection.
- Convincing businesses to sponsor by presenting how the platform could lead to more customers, by allowing them to advertise and do directed marketing by accessing the user data, tracking data and analytics on them.

- Convincing smart service providers to sponsor bandwidth in addition to the bandwidth they should provide for their IoT devices.
- Convincing users to sponsor bandwidth: the user is expected to share bandwidth to be able to utilize the network beyond a cap. This option is effective in a residential community, not in a business community where users are mostly visitors.

In residential areas, a crowdsourcing strategy could be employed for residents to join the wireless network and contribute from their broadband connection [3, 15]. The same strategy would not work in a business district. Rather, a strategy that increases utility of the bandwidth sponsoring businesses and non-profits in the area would be more effective.

. Strategies for platform promotion and positioning

Other strategies include positioning the platform, its launch and promotion. What strategy should the municipality follow while helping community mesh wireless and rolling the smart city services on this network, and meanwhile encouraging private investment? Municipality and communities must appreciate the value of commercial investment in the city, should stay away from any policy or strategy that will deter them. The platform should not be positioned to compete against commercial wireless services and substitutable offerings. It should not be about being a winner in the market. Rather, it should be for serving a real need in the community for a specific purpose and to fill the gap from commercial providers.

Frequency reuse

Frequency reuse is the process of using the same radio frequencies on radio transmitter sites within a geographic area that are separated by sufficient distance to cause minimal interference with each other. Frequency reuse allows for a dramatic increase in the number of customers that can be served (capacity) within a geographic area on a limited amount of radio spectrum (limited number of radio channels). Frequency reuse allows WiMAX system operators to reuse the same frequency at different cell sites within their system operating area.

The number of times a frequency can be reused is determined by the amount of interference a radio channel can tolerate from nearby transmitters that are operating on the same frequency (carrier to interference ratio).

Carrier to interference (C/I) level is the amount of interference level from all unwanted interfering signals in comparison to the desired carrier signal. The C/I ratio is commonly expressed in dB. Different types of systems can tolerate different levels of interference dependent on the modulation type and error protection systems. The typical C/I ratio for narrowband mobile radio systems ranges from 9 dB (GSM) to 20 dB (analog cellular). WiMAX systems can be much more tolerant to interference levels (possibly less than 3 dB C/I) when OFDM and adaptive antenna systems are used.

WiMAX systems may also reuse frequencies through the use of cell sectoring. Sectoring is a process of dividing a geographic region (such as a radio coverage area) where the initial geographic area (e.g. cell site coverage area) is divided into smaller coverage areas (sectors) by using focusing equipment (e.g. directional antennas).

The radio channel signal strength decreases exponentially with distance. As a result, mobile radios that are far enough apart can use the same radio channel frequency with minimal interference.

Without beamforming only reuse type 3x3x3 has acceptable value of outage probability. While using beamforming, while rest of the reuse patterns show acceptable results, network type of reuse 1 with loaded systems (using all available subchannels) will result in significant system outage. However, method of partial usage of subchannels reduced the outage to acceptable level while still maintaining the average throughput at the highest level. By using 80% of total subchannels reuse type 1x3x1 will give good results for both the radio quality and throughput parameters. For loaded systems (using beamforming), it has been concluded that reuse t ype 3x3x1 comes up with the best performance.

OFDM works well in the channels . In multi-cell deployments, in order to avoid intercell interference, basic OFDM requires directional antennas or relatively high frequency-reuse schemes and careful radio-frequency (RF) planning.

OFDMA with its various subcarrier allocation schemes (FUSC and PUSC) improves performance in multi-cell deployments by averaging the interference across multiple cells. The interference becomes a function of cell loading and can be significantly reduced by efficient scheduling. OFDMA systems, on the other hand, are very flexible in terms of RF planning and support a variety of frequency reuse schemes (FRS). These FRS may be described by denotation NcxNsxNf, where

- Nc is number of independent frequency channels in the WiMAX network
- Ns is the number of sectors per cell
- Nf is the number of segments in exploited frequency channel.

Two of these FRS are for instance 1x3x1 and 1x3x3.

Both schemes use three-sector base-stations and require only one RF channel for all sectors and BS, hence opening the door for operators who have limited amount of spectrum.FRS 1x3x1 eliminates the need for any frequency planning. That is a significant advantage especially for heavy urban areas where RF planning is very difficult. FRS 1x3x3 uses different (orthogonal) sets of tones (called “segments”) for each sector of a base-station thereby reducing inter-cell interference and minimizing outage area. This scheme also simplifies RF planning–one need only assign segments to sectors while using the same RF channel among all base-stations.

Since the OFDMA PHY layer has many choices of sub-carrier allocation methods, multiple zones can use different sub-carrier allocation methods to divide each subframe. One benefit of using zone switching is that different frequency schemes can be dynamically deployed in a cell, forming a fractional frequency reuse scheme (FFRS).

The image here shows an example of deploying different FFRS in one frame. For the first half of each frame, the entire frequency band is divided by three and allocated in each

sector. For the second half of each frame, the whole same frequency band is used in each sector.
The benefits of deploying FFRS in one frame are:

- edge users, who are receiving co-channel interference from other sectors in other cells, also have suppressed co-channel interference (CCI)
- users around the cell center have the full frequency band because they are relatively less subject to co-channel interference.

Co-Channel Interference

Co-channel interference or CCI **exists when two or more devices are operating on the same frequency channel.**

Co-channel interference is not actually an interference but more a sort of congestion. It hinders the performance by increasing the wait time as the same channel is used by different devices. The CCI forces other devices to defer transmissions and wait in a queue until the first device finishes using the transmission line and the channel is free.

The frequency reuse method is useful for increasing the efficiency of spectrum usage but results in co-channel interference because the same frequency channel is used repeatedly in different cochannel cells. In most mobile radio environments, use of a seven cell reuse pattern is not sufficient to avoid co-channel interference. Increasing the K value (K>7) would reduce the number of channels per cell, and that would also reduce the spectrum efficiency. Therefore it might be advisable to retain the same number of radios as the seven cell system but to sector the cell radially

Adjacent-channel interference

Adjacent-channel interference (**ACI**) is interference caused by extraneous power from a signal in an adjacent channel. ACI may be caused by inadequate filtering (such as incomplete filtering of unwanted modulation products in FM systems), improper tuning or poor frequency control (in the reference channel, the interfering channel or both).

ACI is distinguished from crosstalk

The adjacent-channel interference which receiver A experiences from a transmitter B is the sum of the power that B emits into A's channel—known as the "unwanted emission", and represented by the ACLR (Adjacent Channel Leakage Ratio)—and the power that A picks up from B's channel, which is represented by the ACS (Adjacent Channel Selectivity). B emitting power into A's channel is called adjacent-channel leakage (unwanted emissions). It occurs for two reasons. First, because RF filters require a roll-off, and do not eliminate a signal completely. Second, due to intermodulation in B's amplifiers, which cause the transmitted spectrum to spread beyond what was intended. Therefore, B emits some power in the adjacent channel which is picked up by A. A receives some emissions from B's channel due to the roll off of A's selectivity filters. Selectivity filters are designed to "select" a channel. Similarly, B's signal suffers intermodulation distortion passing through A's RF input amplifiers, leaking more power into adjacent frequencies.

Mobility and Handoff Management in Wireless Networks

With the increasing demands for new data and real-time services, wireless networks should support calls with different traffic characteristics and different Quality of Service (QoS) guarantees. In addition, various wireless technologies and networks exist currently that can satisfy different needs and requirements of mobile users. Since these different wireless networks act as complementary to each other in terms of their capabilities and suitability for different applications, integration of these networks will enable the mobile users to be always connected to the best available access network depending on their requirements. This integration of heterogeneous networks will, however, lead to heterogeneities in access technologies and network protocols. To meet the requirements of mobile users under this heterogeneous environment, a common infrastructure to interconnect multiple access networks will be needed. Although IP has been recognized to be the de facto protocol for next-generation integrated wireless, for inter-operation between different communication protocols, an adaptive protocol stack is also required to be developed that will adapt itself to the different characteristics and properties of the networks Finally, adaptive and intelligent terminal devices and smart base stations (BSs) with multiple air interfaces will enable users to seamlessly switch between different access technologies.

For efficient delivery of services to the mobile users, the next-generation wireless networks require new mechanisms of *mobility management* where the location of every user is proactively determined before the service is delivered. Moreover, for designing an adaptive communication protocol, various existing mobility management schemes are to be seamlessly integrated. In this chapter, the design issues of a number of mobility management schemes have been presented. Each of these schemes utilizes IP-based technologies to enable efficient roaming in heterogeneous network Efficient handoff mechanisms are essential for ensuring seamless connectivity and uninterrupted service delivery. A number of handoff schemes in a heterogeneous networking environment are also presented in this chapter.

The chapter is organized introduces the concept of mobility management and its two important components- *location management* and *handoff management*presents various network layer protocols for macro-mobility and micro-mobility. discusses various link layer protocols for location management. introduces the concept of handoff. Different types of handoff mechanisms are classified, and the delays associated with a handoff procedure are identified. Some important cross-layer handoff mechanisms are also discussed in presents *media independent handover* (MIH) services as proposed in IEEE 802.21 standards. It also discusses how MIH services can be utilized for designing seamless mobility protocols in next-generation heterogeneous wireless networks. Security issues in handover protocols. Section 8 identifies some open areas of research in mobility management. Section 9 concludes the chapter.

Mobility Management

With the convergence of the Internet and wireless mobile communications and with the rapid growth in the number of mobile subscribers, mobility management emerges as one of the most important and challenging problems for wireless mobile communication over the Internet. Mobility management enables the serving networks to locate a mobile subscriber's point of attachment for delivering data packets (i.e. location management), and maintain a mobile subscriber's connection as it continues to change its point of attachment (i.e. handoff management). The issues and functionalities of these activities are discussed in this section.

Location management

Location management enables the networks to track the locations of mobile nodes. Location management has two major sub-tasks: (i) *location registration*, and (ii) *call delivery* or *paging*. In location registration procedure, the mobile node periodically sends specific signals to inform the network of its current location so that the location database is kept updated. The call delivery procedure is invoked after the completion of the location registration. Based on the information that has been registered in the network during the location registration, the call delivery procedure queries the network about the exact location of the mobile device so that a call may be delivered successfully. The design of a location management scheme must address the following issues: (i) minimization of signaling overhead and latency in the service delivery, (ii) meeting the guaranteed quality of service (QoS) of applications, and (iii) in a fully overlapping area where several wireless networks co-exist, an efficient and robust algorithm must be designed so as to select the network through which a mobile device should perform registration, deciding on where and how frequently the location information should be stored, and how to determine the exact location of a mobile device within a specific time frame.

. Handoff management

Handoff management is the process by which a mobile node keeps its connection active when it moves from one access point to another. There are three stages in a handoff process. First, the initiation of handoff is triggered by either the mobile device, or a network agent, or the changing network conditions. The second stage is for a new connection generation, where the network must find new resources for the handoff connection and perform any additional routing operations. Finally, data-flow control needs to maintain the delivery of the data from the old connection path to the new connection path according to the agreed-upon QoS guarantees. Depending on the movement of the mobile device, it may undergo various types of handoff. In a broad sense, handoffs may be of two types: (i) intra-system handoff (horizontal handoff) and (ii) inter-system handoff (vertical handoff). Handoffs in homogeneous networks are referred to as intra-system handoffs. This type of handoff occurs when the signal strength of the serving BS goes below a certain threshold value. An inter-system handoff between heterogeneous networks may arise in the following scenarios - (i) when a user moves out of the serving network and enters an overlying network, (ii) when a user connected to a network chooses to handoff to an underlying or overlaid network for his/her service requirements, (iii) when the overall load on the network is required to be distributed among different systems.

The design of handoff management techniques in all-IP based next-generation wireless networks must address the following issues: (i) signaling overhead and power requirement for processing handoff messages should be minimized, (ii) QoS guarantees must be made, (iii) network resources should be efficiently used, and (iv) the handoff mechanism should be scalable, reliable and robust.

Mobility management at different layers

A number of mobility management mechanisms in homogeneous networks have been presented and discussed in (Akyildiz et al., 1999). Mobility management in heterogeneous networks is a much more complex issue and usually involves different layers of the TCP/IP protocol stack. Several mobility management protocols have been proposed in the literature for next-generation all-IP wireless networks. Depending on the layers of communication protocol they primarily use, these mechanisms can be classified into three categories – protocols at the networks layer, protocols at the link layer and the cross-layer protocols. Network layer mobility protocols use messages at the IP layer, and are agnostic of the underlying wireless access technologies Link layer mobility mechanisms provide mobility-related features in the underlying radio systems. Additional gateways are usually required to be deployed to handle the inter-operating issues when roaming across heterogeneous access networks. In link layer protocols, handoff signals are transmitted through wireless links, and therefore, these protocols are tightly-coupled with specific wireless technologies. Mobility supported at the link layer is also called *access mobility* or *link layer mobility* The cross-layer protocols are more common for handoff management. These protocols aim to achieve network layer handoff with the help of communication and signaling from the link layer. By receiving and analyzing, in advance, the signal strength reports and the information regarding the direction of movement of the mobile node from the link layer, the system gets ready for a network layer handoff so that packet loss is minimized and latency is reduced.

Network Layer Mobility Management Mechanisms

Over the past several years, a number of IP mobility management protocols have been proposed. Different mobility management frameworks can be broadly distinguished into two categories - device mobility management protocol for localized or *micro-mobility* and protocols for inter-domain or *macro mobility*. The movement of a mobile node (MN) between two subnets within one domain is referred to as micro-mobility. For example, the movement of MN from subnet *B* to subnet *C* is an example of micro-mobility. An example of micro-mobility in UMTS Terrestrial Radio Access Networks (UTRAN) is movement of an MN from one BS to another, both BSs belonging to the same *random access network* (RAN), while in WLAN it is a node movement between two *access points* (APs). The movement of devices between two network domains is referred to as macro-mobility. For example, the movement of MN from domain 1 to domain 2 in Figure 1 is an example of macro-mobility. A domain represents an administrative body, which may include different access networks, such as WLAN, second-generation (2G), and third-generation (3G) networks Next-generation all-IP wireless network will include various heterogeneous networks, each of them using possibly different access technologies. Therefore, satisfactory macro-mobility solution supporting all these technologies is needed.

Macro-mobility protocols

Mobile IP is the most widely used protocol for macro-mobility management. In addition to Mobile IP, three macro-mobility architectures are discussed in the section. These protocols are: Session Initiation Protocol (SIP)-based mobility management, multi-tier hybrid SIP and Mobile IP protocol, and network inter-working agent-based mobility protocol.

Mobile IP: Mobile IP (Perkins, 2008) is the most well-known macro mobility scheme that solves the problem of node mobility by redirecting the packets for the MN to its current location. It introduces seven elements: (i) *Mobile node* (MN) – a device or a router that can change its point of attachment to the Internet, (ii) *Correspondent node* (CN) – the partner with which MN communicates, (iii) *Home network* (HN) – the subnet to which MN belongs, (iv) *Foreign network* (FN) – the current subnet in which the MN is visiting, (v) *Home agent* (HA) – provides services for the MN and is located in the HN, (vi) *Foreign agent* (FA) – provides services to the MN while it visits in the FN, (vii) *Care-of-address* (CoA) – defines the current location of the MN; all packets sent to the MN are delivered to the CoA. Mobile IP protocol has three steps: (i) agent discovery, (ii) registration, and (iii) routing and tunneling.

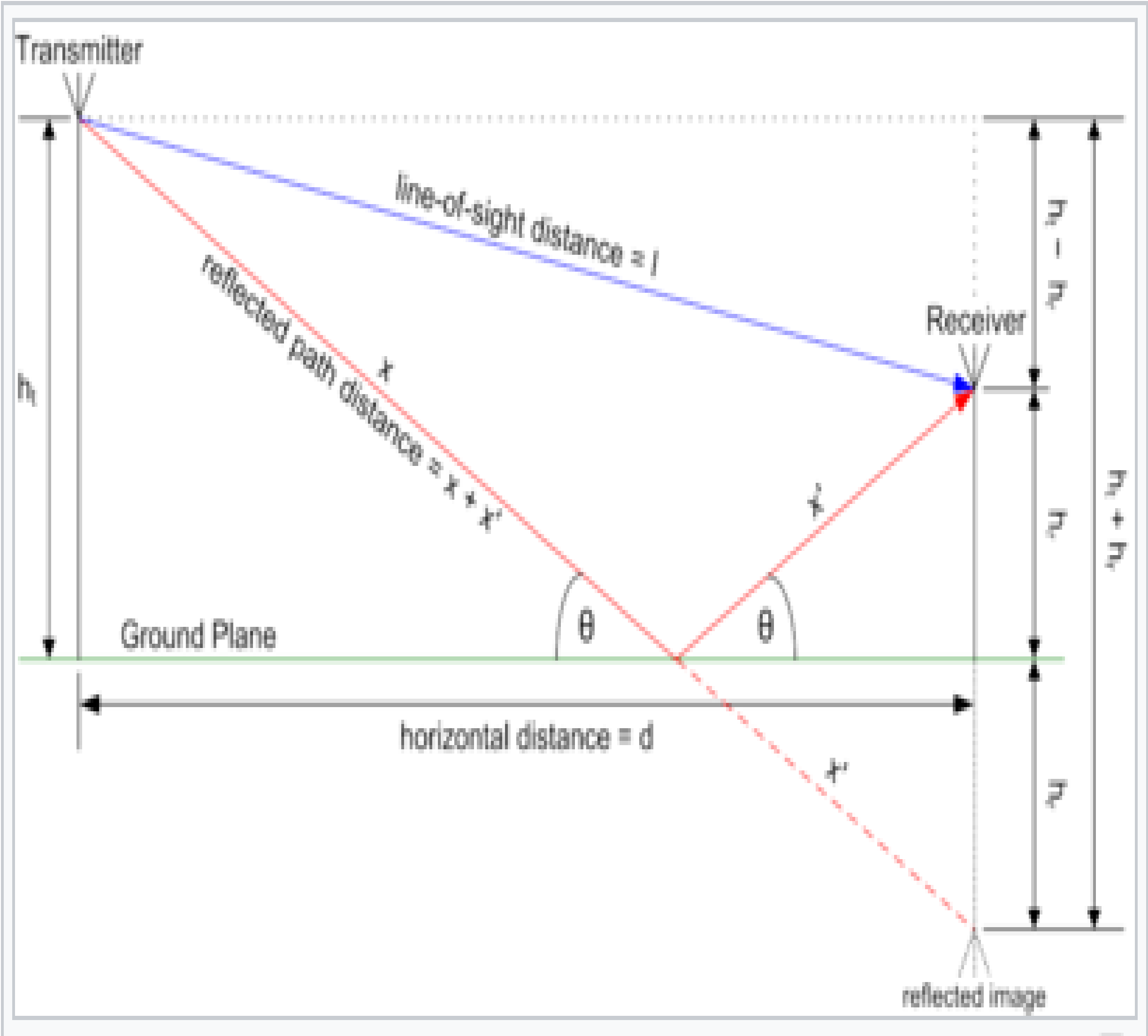
Agent discovery: An MN is able to detect whether it has moved into a new subnet by two methods – agent advertisement and agent solicitation. In the agent advertisement method, FAs and HAs advertise their presence periodically using agent advertisement messages. These advertisement messages can be seen as beacon broadcasts into the subnets. An MN in a subnet can receive agent advertisements. If no agent advertisement messages are found or the inter-arrival time is too high, the MN may send agent solicitations. After the step of agent advertisement or solicitation, the MN receives a CoA. The CoA may be either an FA or a co-located CoA (Perkins, 2008). A co-located CoA is found by using Dynamic Host Configuration Protocol (DHCP) or Point-to-Point Protocol (PPP).

Registration: After the MN receives its CoA, it registers it with the HA. The main objective of the registration is to inform the HA about the current location of MN. The registration may be done in two ways depending on the location of the CoA. If the CoA is the FA, the MN sends its registration request to the FA which in turn forwards it to the HA. If the CoA is co-located, the MN may send the request directly to the HA.

Routing and tunneling: When a CN sends an IP packet to the MN, the packet is intercepted by the HA. The HA encapsulates the packet and tunnels it to the MN’s CoA. With FA CoA, the encapsulated packet reaches the FA serving the MN. The FA decapsulates the packet and forwards it to the MN. With co-located CoA, the encapsulated packets reach the MN, which decapsulates them. In Figure 1, the tunneling (step b) ends at the MN instead of at the FA.

Two-ray ground-reflection model

The Two-Rays Ground Reflected Model is a radio propagation model which predicts the path losses between a transmitting antenna and a receiving antenna when they are in LOS (line of sight) . Generally, the two antenna each have different height. The received signal having two components, the LOS component and the multipath component formed predominantly by a single ground reflected wave.



$$r_{los}(t) = Re\left\{\frac{\lambda\sqrt{G_{los}}}{4\pi} \times \frac{s(t)e^{-j2\pi l/\lambda}}{l}\right\}$$

and the ground reflected component may be written as

$$r_{gr}(t) = Re\left\{\frac{\lambda\Gamma(\theta)\sqrt{G_{gr}}}{4\pi} \times \frac{s(t-\tau)e^{-j2\pi(x+x')/\lambda}}{x+x'}\right\}$$

where $s(t)$ is the transmitted signal, l is the length of the direct line-of-sight (LOS) ray, $x + x'$ is the length of the ground-reflected ray, G_{los} is the combined antenna gain along the LOS path, G_{gr} is the combined antenna gain along the ground-reflected path, λ is the wavelength of the transmission ($\lambda = \frac{c}{f}$, where c is the speed of light and f is the transmission frequency), $\Gamma(\theta)$ is ground reflection coefficient and τ is the delay spread of the model which equals $(x + x' - l)/c$. The ground reflection coefficient is[1]

$$\Gamma(\theta) = \frac{\sin\theta - X}{\sin\theta + X}$$

where $X = X_h$ or $X = X_v$ depending if the signal is horizontal or vertical polarized, respectively. X is computed as follows.

$$X_h = \sqrt{\varepsilon_g - \cos^2\theta},\ X_v = \frac{\sqrt{\varepsilon_g - \cos^2\theta}}{\varepsilon_g} = \frac{X_h}{\varepsilon_g}$$

The constant ε_g is the relative permittivity of the ground (or generally speaking, the material where the signal is being reflected), θ is the angle between the ground and the reflected ray as shown in the figure above.

From the geometry of the figure, yields:

$$x + x' = \sqrt{(h_t + h_r)^2 + d^2}$$

and

$$l = \sqrt{(h_t - h_r)^2 + d^2},$$

Therefore, the path-length difference between them is

$$\Delta d = x + x' - l = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}$$

and the phase difference between the waves is

$$\Delta\phi = \frac{2\pi\Delta d}{\lambda}$$

The power of the signal received is

$$P_r = E\{|r_{los}(t) + r_{gr}(t)|^2\}$$

where $E\{\cdot\}$ denotes average (over time) value.

Approximation [edit]

If the signal is narrow band relative to the inverse delay spread $1/\tau$, so that $s(t) \approx s(t-\tau)$, the power equation may be simplified to

$$P_r = E\{|s(t)|^2\}\left(\frac{\lambda}{4\pi}\right)^2 \times \left|\frac{\sqrt{G_{los}} \times e^{-j2\pi l/\lambda}}{l} + \Gamma(\theta)\sqrt{G_{gr}}\frac{e^{-j2\pi(x+x')/\lambda}}{x+x'}\right|^2 = P_t\left(\frac{\lambda}{4\pi}\right)^2 \times \left|\frac{\sqrt{G_{los}}}{l} + \Gamma(\theta)\sqrt{G_{gr}}\frac{e^{-j\Delta d}}{x+x'}\right|^2$$

where $P_t = E\{|s(t)|^2\}$ is the transmitted power.

When distance between the antennas d is very large relative to the height of the antenna we may expand $\Delta d = x + x' - l$,

$$\Delta d = x + x' - l = d\left(\sqrt{\frac{(h_t + h_r)^2}{d^2} + 1} - \sqrt{\frac{(h_t - h_r)^2}{d^2} + 1}\right)$$

using the Taylor series of $\sqrt{1+x}$:

$$\sqrt{1+x} = 1 + \tfrac{1}{2}x - \tfrac{1}{8}x^2 + \dots,$$

and taking the first two terms only,

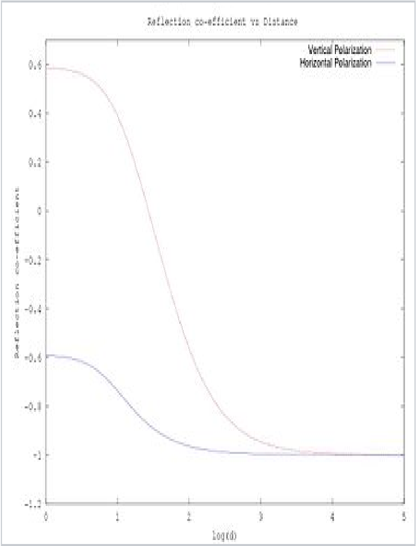
$$x + x' - l \approx \frac{d}{2} \times \left(\frac{(h_t + h_r)^2}{d^2} - \frac{(h_t - h_r)^2}{d^2} \right) = \frac{2h_t h_r}{d}$$

The phase difference can then be approximated as

$$\Delta\phi \approx \frac{4\pi h_t h_r}{\lambda d}$$

When d is large, $d \gg (h_t + h_r)$,

$$d \approx l \approx x + x',\ \Gamma(\theta) \approx -1,\ G_{los} \approx G_{gr} = G$$



Reflection co-efficient tends to -1 for large d.

and hence

$$P_r \approx P_t \left(\frac{\lambda \sqrt{G}}{4\pi d} \right)^2 \times |1 - e^{-j\Delta\phi}|^2$$

Expanding $e^{-j\Delta\phi}$ using Taylor series

$$e^x = \sum_{n=0}^{\infty} \frac{x^n}{n!} = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \cdots$$

and retaining only the first two terms

$$e^{-j\Delta\phi} \approx 1 + (-j\Delta\phi) + \cdots = 1 - j\Delta\phi$$

it follows that

$$P_r \approx P_t \left(\frac{\lambda \sqrt{G}}{4\pi d} \right)^2 \times |1 - (1 - j\Delta\phi)|^2$$

$$= P_t \left(\frac{\lambda \sqrt{G}}{4\pi d} \right)^2 \times \Delta\phi^2$$

$$= P_t \left(\frac{\lambda \sqrt{G}}{4\pi d} \right)^2 \times \left(\frac{4\pi h_t h_r}{\lambda d} \right)^2$$

$$= P_t \frac{G h_t^2 h_r^2}{d^4}$$

so that

$$P_r \approx P_t \frac{G h_t^2 h_r^2}{d^4}$$

which is accurate in the far field region, i.e. when $\Delta\phi \ll 1$ (angles are measured here in radians, not degrees) or, equivalently,

$$d \gg \frac{4\pi h_t h_r}{\lambda}$$