Redline Communications Inc.

Combining Fixed and Mobile WiMAX Networks

Supporting the Advanced Communication Services of Tomorrow

WiMAX Whitepaper

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The introduction of certified and interoperable WiMAX technology solutions has spurred a spirited discussion on how best to combine fixed and mobile infrastructure solutions to create one, cohesive network. This paper seeks to demonstrate that such an approach poses significant challenges due to the differing characteristics of fixed and mobile networks, leading to a diverse set of requirements for coverage and interference thresholds. This paper will also discuss the importance of operators achieving the highest possible spectral efficiency – a key component of any successful profitable business model.

We begin the analysis by discussing interference in wireless networks and providing an overview of frequency planning. This paper includes carrier-to-interference requirements as this significantly influences network capacity. We will also provide an overview of key aspects of cellular frequency reuse which leads us to discuss spectral efficiency in cellular networks. We then outline the differences between fixed and mobile networks before demonstrating reasons for considering the independent operation of fixed and mobile networks. Finally, we summarize a study to show that for the same access technology, fixed networks have more than twice the spectral efficiency of mobile networks.

Overview of Frequency Planning

Spectrum is the scarce resource and the 'raw material' for wireless telecommunications. Frequency planning then represents a key function in the design of wireless networks to make best use of the available spectrum and to derive the highest utilization and network efficiency. This helps accelerate an operator's return on their network investment by enabling them to profitably deliver the high margin service offerings their customers demand.

The purpose of frequency planning is to ensure that an acceptable level of carrier-to-interference ratio (CIR) is supported by the wireless network to assure proper communication that meets operator requirements while making best use of the available spectrum. Proper communication implies meeting throughput and other quality of service (QoS) requirements including coverage objectives as set by the carrier and which meets the necessary requirements set by the wireless access technology.

Frequency planning involves the task of assigning channels to cellular base stations such that co-channel and adjacent channel interference does not exceed the CIR requirements in the serving cell. This activity depends on the choice of wireless access technology (e.g. GSM, CDMA, WiMAX) since each technology has their own distinct and specific requirements. Frequency planning also depends on the network topography such as the number of sectors in a cell site and the orientation of these sectors. Finally, with the advent of broadband wireless access technologies featuring link adaptation techniques (e.g. adaptive modulation and coding), frequency planning has a direct impact on the overall network throughput.

Carrier-to-Interference Ratio Requirements

Different technologies have different requirements for CIR depending on multiple factors including modulation and forward error correction coding. For example, the old AMPS systems use CIR of 17 dB, GSM systems are typically planned for CIR of 13 dB, the Motorola iDEN system uses CIR of 21 dB, and cdma One systems (IS95) use an E_b/N_0 of -5 dB (ratio of energy per bit to noise).

Fixed and mobile WiMAX features link adaptation techniques where higher modulation and lower coding schemes are used depending on the link quality. These schemes are summarized in Table 1 along with the required CIR necessary to decode the corresponding signal.

Modulation/Coding Rate	Fixed WiMAX Rx CIR (dB) (802.16-2004)	Mobile WiMAX Rx CIR (with CTC) (dB) (802.16e-2005)
BPSK 1/2	3	n/a
QPSK 1/2	6	2.9
QPSK 3/4	8.5	6.3
16QAM 1/2	11.5	8.6
16QAM 3/4	15	12.7
64QAM 2/3	19	16.9
64QAM 3/4	21	18

Table 1 SNR Requirements per modulation and coding mode for WiMAX.

As illustrated, CIR significantly impacts throughput since higher CIR allows higher modulation rates and lower coding rates resulting in higher throughput and increased spectral efficiency. This is a generally accepted theory that is clearly represented by Shannon's capacity equation:

$$C = B \times \log_2(1+CIR)$$

Where C is the channel capacity, B is the channel bandwidth. Therefore, channel capacity is directly proportional to channel bandwidth and CIR.

Carrier-to-interference ratio impacts coverage since in areas where CIR falls below the required minimum level to demodulate a signal, an 'outage' area exist where a subscriber is denied service. Operators must therefore be aware of their CIR ratios so that they may build accurate business models and effective cell plans that will meet their network requirements.

Cellular Reuse

In a cellular network frequencies are assigned to cells in an appropriate manner to meet the CIR requirements. The most popular cellular configuration is a three-120º sectored cell. Table 2 shows a theoretically achievable median CIR for a three-sectored cell network topology with different power decay and frequency reuse factors (K). It assumes an infinite number of tiers and omni-directional antennas at the subscriber equipment. A reuse of 3 implies that a total of 3 × 3 = 9 channels are required for the frequency plan.

Power Decay Factor (n)	Reuse Factor (K)				
	3	4	7	9	12
2	n/a	n/a	n/a	n/a	n/a
2.5	3.8	5.3	8.4	9.7	11.3
3	7.8	9.7	13.3	14.9	16.8
3.5	10.9	13.1	17.3	19.2	21.4
4	13.7	16.2	21.0	23.2	25.7

Table 2 Median C/I for three-sectored cellular wireless networks for various cell reuse factor.

Table 2 leads to two important conclusions:

1- Higher CIR is achievable with a larger frequency reuse factor. This is because the distance between co-channel cells is large; hence the interference power in the serving cell is smaller.

2- Higher CIR is achievable with larger power decay. Alternatively, we can see that the cellular system would not be possible in environments where the power decay factor is small.

For instance, in the case of free-space propagation ($n = 2$), the carrier-to-interference ratio is too large to allow for small reuse factor. Note that the higher the transmitter and receiver are placed above ground, the lower the power decay factor (less path loss).

In typical suburban environments, like those found in North America, the power decay factor is about 3.3, while power decay factor for urban areas is as high as 4, and in some instances even higher. Correlating such power decay factors with the requirements of some of the stated technologies above, we find that AMPS systems were typically planned for a frequency reuse of 7, GSM networks are planned for a frequency reuse of 4, and cdmaOne networks are planned with a frequency reuse of 1.

Spectral Efficiency

Spectral efficiency (measured in bits/second/Hertz) is a function of the cell capacity and the utilized spectrum. It can be expressed by the following equation:

$$\text{Spectral Efficiency} = C / (K \times B)$$

We have seen that the higher the CIR the larger the capacity. However, a higher CIR requires a larger frequency reuse factor. Enhancing the spectral efficiency of a wireless access technology involves the challenging task of improving throughput while mitigating the effects of interference by reducing the frequency reuse factor. This is achieved, in part, with a better physical layer design that includes advanced coding and by using multiple antenna elements with adaptive signal processing techniques.

In short, spectral efficiency of an access technology is impacted by the frequency reuse factor. The smaller the reuse factor the more spectrally efficient the network will be for a particular access technology.

Fixed and Mobile Cell Sizes

In the previous sections we have demonstrated the dependency of channel capacity on the CIR and illustrated how spectral efficiency is impacted by the frequency reuse factor. Here, we delve into the distinct characteristics of fixed and mobile systems to illustrate the important differences in the design of these networks that lead us to determine the expected performance outcomes.

Fixed wireless networks are characterized by stationary wireless devices and typically include outdoor customer premises equipment (CPE) or an indoor desktop CPE. Since the subscriber is stationary the CPE is not required to be small in size as to allow portability, and is not required to draw power from a battery. Therefore, CPEs in fixed applications traditionally feature the following attributes:

1. High-gain antenna: due to larger available size, there is more space to integrate a higher gain antenna. Moreover, since the CPE is stationary, it can be oriented in the direction of the serving cell, hence omni-directional antennas are not required and a directional antenna is more desired to improve system gain. The directional antenna reduces interference. This is a key point and a major differentiator between fixed and mobile networks and, as we shall see later, has a direct impact the enhancing the spectral efficiency of fixed networks. Typical antenna gain on fixed CPEs is 6-15 dB.

2. High output power: since battery life is not a concern, fixed CPEs feature higher output power than mobile devices. Moreover, the larger size of fixed CPEs allow for larger heat dissipation, hence increasing the potential to implement a high-power transmitter.

Alternatively, mobile networks have to account for mobile users who require ease of portability for a host of emerging communication devices that necessitate extended battery life. These mobile devices have the following characteristics:

1. Low-gain antenna: due to their limited size, the antenna is typically a low gain omni-directional antenna (typically 0 dBi).

2. Low transmit power: high-power transceivers consume more energy which shortens battery life. Furthermore, the limited space in the handset limits heat dissipation capabilities leading designers to use lower transmit power.

Another difference between fixed and mobile networks is the channel characteristic. Mobile networks are usually characterized by a high fading channel whereas in a fixed network the distinct absence of mobility leads to less fading. Fading decreases signal quality as demonstrated by lowering the signal-to-noise ratio. In the radio frequency design, a margin is factored to account for fading which leads to a reduction in the maximum allowable path loss, thereby decreasing the size of the cell. Since fading is more severe in a mobile environment, a higher fade margin is added in a mobile network design than in a fixed network design.

Another significant difference between fixed and mobile networks lies in the manner in which subscriber devices are used. A mobile device is typically used at a low height above the ground – no higher than the user's ear. On the other hand, fixed devices are typically at used at higher elevations from the ground: desktop CPEs in multi-tenant units and wall-mount outdoor CPEs are typically at a higher elevation. This results in less path loss between the transmitter and the receiver in a fixed network. This lower allowable path loss results in larger cell sizes.

Hybrid Fixed and Mobile Operation

Differences in equipment features, channel characteristics and usage models leads to larger cell sizes in fixed networks than those found in mobile networks. This fact makes mixing fixed (outdoor and indoor devices) and mobile handheld units in one network a challenging proposition for several reasons. We will focus our discussion on one such reason, which, in our opinion, is most important to the operator: spectrum utilization.

When ubiquitous coverage is required to support mobile services, the resulting effect is a increase in the number of cells in that network. However, since the range of mobile devices is limited and the range for fixed devices is large, a large area of overlap between cells is necessary to enable coverage ubiquity for mobile devices within the network design. Consequently, an increase in the amount of interference is present in hybrid networks leading to reduced performance for both fixed and mobile devices in the network.

We have seen that interference limits throughput as increased CIR leads to lower channel capacity. Introducing a mix of fixed and mobile devices on one network only compounds the situation and increases the amount of interference and reduces throughput and the spectrum utilization efficiency of the network. To achieve high spectral efficiency and to fully utilize scarce and expensive spectrum, it is clear that a two network strategy is recommended in order to achieve financial, technical and operational objectives.

Spectral Efficiency in Fixed and Mobile Networks

Having demonstrated that maximizing spectral efficiency calls for separating the operation of fixed and mobile networks, we note here that the spectral efficiency of fixed networks is higher than that of mobile networks. This argument was proven in [1] which we summarize partially here for the case of WiMAX (OFDM-256). Table 3 shows the parameters for the wireless network.

The same access scheme is used in two comparable networks: a mobile network with omni-directional antennas on the subscriber device and a fixed network with directional antennas on the subscriber device. Two traffic models were used. The first is the equal mean packet call duration for all subscribers (EMPC-D).

This model is typically optimistic as it leads to higher throughput in a sector as subscribers with good radio links will receive higher data rates than subscribers with poor radio links. The second assumes an equal mean packet call volume per subscriber (EMPC-V) which leads to reduced capacity and spectrum efficiency numbers as subscribers under poor radio conditions consume a disproportionately larger amount of radio resources.

Parameter	Value
Number of sites	16 wrapped around on torus. 3 sectors per site, hexagonal deployment
Site-to-site distance	900 m (300 m cell radius)
Frequency reuse pattern	1x3
Channel bandwidth	3.5 MHz
Frequency band	3.5 GHz
User distribution	uniform, random positioning
Pathloss slope	38 dB per decade
Propagation Model	COST-231
BS RF TX power	2 W
BS antenna	65º, 17.5 dBi, 35 m above ground. No downtilt
Mobile antenna	Omni, 0 dBi: 1.5 m above ground
Fixed terminal antenna	Directive, 17 dBi: 6 m above ground
Power control	Off
Slow fading std. deviation	8 dB
Traffic model	Equal mean packet call duration (EMPC-D) Equal mean packet call volume (EMPC-V)

Table 3 Network Model Parameters.

Table 4 shows the resulting spectral efficiency for the two traffic models. Note that in either situation the spectral efficiency of a fixed network is more than twice that of a mobile network. In this case we assume that the directive antenna of the subscriber unit in fixed networks is in alignment with the base station antenna and is one of the main reasons for these results.

Network Type	EMPC-D	EMPC-V
Fixed	1.33	0.94
Mobile	0.66	0.41

Table 4 Spectral efficiency (b/s/Hz) per sector for fixed and mobile WiMAX networks

Conclusion

We reviewed in some detail basic frequency planning concepts which were used to make the argument that for efficient utilization of spectral resources a two network approach (fixed and mobile) is recommended. With frequency spectrum being the scarce and, in many cases, expensive resource for wireless communication, it is essential to utilize it most efficiently. Leveraging basic principles, we demonstrated that the equipment features and usage models in fixed and mobile scenarios lead to different cell sizes which make combining the operation of the two modes inefficient from a spectral utilization perspective. We also discussed the results of a study where it was proven that fixed networks have at least twice the spectral efficiency of mobile networks for a given access technology.

Operators must seriously take into account the potential impact on spectrum efficiency and network throughput when considering a combination of fixed and mobile capabilities in their networks. While there may initially appear to be some attractive and immediate benefits in doing so, operators must have a very clear understanding of the performance characteristics they expect of their networks before deploying a combination of fixed and mobile network technologies. This will allow operators to optimize their network performance and protect their considerable technology investments for years to come.

References

[1] C.F. Ball, E. Humburg, K. Ivanov, “Spectrum Efficiency Evaluation for Different Wireless Technologies Based on Traffic Modeling”, IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications, Vol. 3, pp. 2055-2061, Sept. 2005.

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