Second Generation

High-Capacity Broadband Wireless Solutions

Redline communications

Revision 1.0

Executive Summary

This paper describes OFDM (Orthogonal Frequency Division Multiplexing) and its use in second-generation wireless applications. It is intended for network planners and technologists who are responsible for the planning and design of Fixed Broadband Wireless Solutions. This paper describes the market requirements for next generation high capacity wireless applications, the features of OFDM and its advantages, and discusses other desirable features of a high capacity broadband fixed wireless device.

About Redline Communications Inc.

Founded in 1999, Redline Communications, a privately held company, is an innovative provider of second-generation broadband fixed wireless systems for service providers and enterprise markets. Redline has introduced an unprecedented product portfolio incorporating several novel technologies to deliver exceptionally high-speed data rates, under complete non line of sight (NLOS) and challenging multipath deployment conditions, and at significant ranges –to quickly maximize operator return on investment. Redline's leading product, the AN-50, has already received a number of Industry accolades, including the prestigious SuperQuest award at Supercomm in Atlanta for 'Most Promising Transport Technology'.

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1 Introduction

World standards bodies including IEEE are selecting OFDM as the physical link interface of choice for next generation technologies, due to its superior performance in fixed wireless environments. This paper will review the requirements for next generation high capacity wireless applications from the perspective of service providers, and discuss the unique ability of OFDM-based wireless systems to address those capabilities.

2 Market Requirements for Next Generation High-capacity Wireless Applications

2.1 High-capacity

The demand for high capacity broadband links continue to escalate as users implement multimedia applications using graphical data, voice and video. The broadband need applies to both higher speed first mile access, and higher capacity backhaul links. Broadband fixed wireless solutions are a feasible solution that replace and complement implementations using conventional fiber and copper deployment.

2.2 High link availability

The requirement for high data network availability is increasingly being compared to the expectations of power and telephony network operators. When service providers choose wireless as an alternative, they need to engineer the solution to provide the highest standard of reliability. This is especially true for backhaul links that can be carrying the traffic of hundreds or thousands of users. Links that support 1×10^{-9} BERs (bit error rates) are needed to ensure PERs (packet error rates) of 1×10^{-6} or less. Higher packet error rates can sometimes be corrected by a higher-level protocol like TCP, however the cost to performance rapidly escalates. To be practical, wireless technologies must support these low BER's while maintaining range and high speed, even during changing link conditions. Susceptibility to fading effects from weather, and local multi-path conditions are not acceptable.

2.3 High spectrum efficiency

Spectrum is a fixed resource. Regardless whether one is considering using licensed or unlicensed spectrum; one has to always keep in mind the real value of spectrum effectiveness. Spectrum efficiencies translate either into using less spectrum for given data rate achieved, or getting the highest possible data rate from a given amount of spectrum. Today's service providers can now achieve net rates greater than 3 bps / Hz.

2.4 Non Line-of-sight capabilities

With previous wireless technologies, most service providers have suffered the frustration of not being able to service a willing customer because of limited Line of Sight (LOS) conditions. The ability to overcome obstacles like buildings, trees, and hills improves the revenue opportunity for a service provider, or alternately can reduce the capital expenditures (CAPEX) and operating expenditures (OPEX) to complete a wireless link.

2.5 Maximum Coverage

A service provider usually wishes to maximize the number of subscribers that are within the service area. A low coverage rate means that a large percentage of potential subscribers cannot reliably be serviced. Characteristics that would increase coverage would allow lower rooftops to be used. Coverage in the wireless world can be limited by a number of factors such as LOS, distance, and link quality. The robustness and flexibility of next generation wireless solutions address these limitations and enable the service providers to deploy faster and with fewer design constraints. Next generation systems offer the following benefits:

- LOS not always required
- Distances exceeding 50 Miles
- Built-in mechanisms to handle variation in the RF environment and fade margins
- Transparent built-in error correction design to avoid relying on TCP

2.6 Lower cost of implementation and installation

Up front installation costs are a significant drain on the financial resources of a service provider. Critical installation costs include RF planning and surveying, antenna acquisition and placement, cable purchase and installation, and tower or rooftop acquisition costs. For subscriber installations, the costs of surveying subscriber sites that cannot be reached by conventional radio technology are particularly wasteful of resources.

Service providers look to next generation wireless technologies to benefit from the smaller foot-print of the required equipment and associated antennas, easier to install and aim antennas, lower cost and easier to install cables, and being able to install antennas much lower on a tower or a rooftop. Next generation technology also allows operators to avoid the need for penetrating rooftop installation, as the new technologies are capable to handle some degree of movement in the antenna. This translates in much simpler and less expensive rooftop leasing arrangements.

2.7 Lower cost of operation

Ongoing monthly costs can rapidly overshadow initial capital expenditures. The cost of locating high on towers to achieve adequate LOS positioning usually increases monthly costs. The cost of support of links that become unreliable due to fading or antenna repositioning is a hard cost. Operators can provide their own backhaul to eliminate the monthly cost of purchasing backhaul from a third party. This is especially true when the third-party is a key competitor or the incumbent. Next generation wireless technologies allow for greater network planning flexibility and enables a faster ROI in the incumbent bypass strategies.

2.8 Speed to market

Many service providers can take advantage of a rapid provisioning capability. The ability to provide a high-speed link to a commercial customer within days of order is a competitive advantage. Wireless has long been recognized as a quick means to market. With next generation technology, operators can quickly deploy a link as a proof of concept, without having to secure roof-rights and complex leasing arrangements. In a few hours, an operator can determine if the technology will be suitable.

3 Orthogonal Frequency Division Multiplexing

3.1 OFDM – Introduction and History

OFDM technology has been around for decades. However it has not been practical to use in a fixed wireless deployment until recently because of the high computational (and therefore silicon) costs associated with its implementation. It is only recently that the cost of digital processing technology has become economical to apply OFDM to commercial fixed wireless applications.

OFDM has been used successfully in wire-line access applications, such as Digital Subscriber Line (DSL) modems, and wireless local area networks (WLAN's) where throughput is at a premium and channel conditions severely impair the performance of alternative encoding and modulation schemes. OFDM has also been used in the digital video broadcast industry throughout Europe for many years to address harsh multi-path disturbances arising from long-range television transmissions.

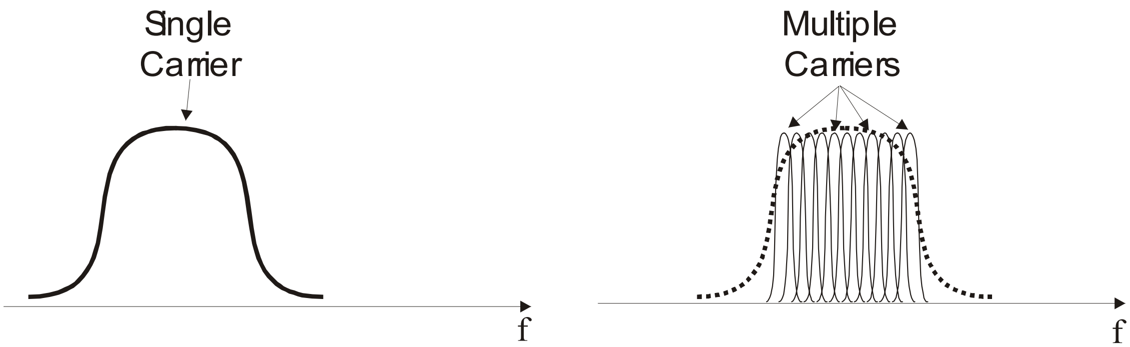
The key benefits of OFDM include:

- Higher spectrum efficiency, translating into high data speeds in a smaller amount of spectrum than competing technologies.

- High resistance to multi-path interference, and frequency specific fading, leading to better performance in non line of sight conditions.

3.2 The essence of OFDM

The essence of OFDM is that it breaks up the transmitted signal into many smaller signals, as shown in the figure below.



For example, instead of one signal carrying 72 Mbps of data, there are 48 separate carriers, each carrying about 1.5 Mbps of data (in the case of the Redline product).

One key aspect of OFDM implementation is that the individual carriers overlap significantly to preserve overall bandwidth. Normally, overlapping signals would interfere with each other, however, through special signal processing, the carriers in an OFDM waveform are spaced in such a manner that they effectively do not see each other, i.e. they are orthogonal to each other.

3.3 OFDM Advantages

3.3.1 Protection against multi-path interference

Multipath interference is a significant problem in long-range links, and in near-line, and non-line of sight links. Multipath is a form of self-interference that occurs when reflections of a signal arrive slightly later than the primary signal. The result can be destructive interference that can essentially null out the primary signal or overlap the original signal such that it cannot be decoded. Multi-path interference is a problem with long-range links where reflections off the ground, snow and water frequently interfere with the primary signal. It is also a problem in urban environments where the signal reflects off buildings and trees and hard concrete.

Multipath interference may cause individual narrowband channels to be altogether lost. This problem is addressed in the Redline implementation in three ways:

by equalizing the received signal based on an estimate of the channel fading conditions (‘bumping back up the faded sub-channels) by interleaving the data before modulation onto the individual sub-channels (so that adjacent data symbols do not necessarily end up on adjacent sub-channels, and thus deep fades do not impair large chunks of the signal)

by convolutional encoding of the input data, which introduces correlations between signal samples that end up on sub-channels occurring in separate parts of the spectrum, which allows the receiver to infer the values of the signal that had ended up on fatally faded sub-carriers. The key advantage of multiple carriers is that the signal is more robust to multipath disturbance, as described below.

3.3.2 Adaptive Modulation and Adaptive Coding

In addition to OFDM itself, Redline's OFDM implementation allows the transmitter and receiver to negotiate an optimal transmission rate for challenging channel conditions adaptively, by:

estimating the channel conditions periodically

adjusting the modulation index (the number of bits per symbol per Hertz) transmitted on each sub-channel

adjusting the coding rate used for each sub-channel.

3.3.3 Getting Around Deep Fades

Sometimes it is impossible to combat sharp, multipath-related fading, even with OFDM systems that use the latest equalization and coding techniques. For this reason, Redline's OFDM implementation uses a guard interval between each of the 48 sub-channels. A guard interval is essentially redundant data taken from the end of the same channel symbol and repeated at the beginning of each channel symbol. Multipath 'echoes' from each individual sub-channel "fall into" the guard interval, rather than "falling onto" each other – and thus causing inter-symbol interference. The use of a guard interval does not add significant complexity to the receiver. Used in conjunction with adaptive equalization, coding and modulation, it is a powerful multipath-combating technique than enables broadband throughput in a wide class of Non-Line-of-Sight environments.

How OFDM with guard interval protection beats Inter-Symbol-Interference

If for example the OFDM carrier were carrying a relatively slow 250,000 symbols per second, then it would take 4 microseconds for each symbol to arrive. At the speed of light, in 4 microseconds a radio signal would travel about ¾ of a mile. So in our example, a reflection would have to travel an extra ¾ of mile before it would overlap a later symbol. Since most reflections travel a much lower extra distance, an OFDM receiver can compensate for reflections, resulting in no lost signal. A non-OFDM single carrier scheme operating at the same rated data rate would have to carry 250,000x48=12,000,000 symbols/sec. The reflected signal would only have to travel 1/48th as far, (or about an extra 83 feet) before one symbol could completely overlap a later symbol resulting in inter-symbol-interference.

3.3.4 Robust protection against co-channel interference

Redline's products feature techniques to increase resistance and robustness against co-channel interference. With more robustness against co-channel interference, the operator can configure an aggressive frequency reuse scheme to maximize data throughput in a given network.

3.4 OFDM Benefits

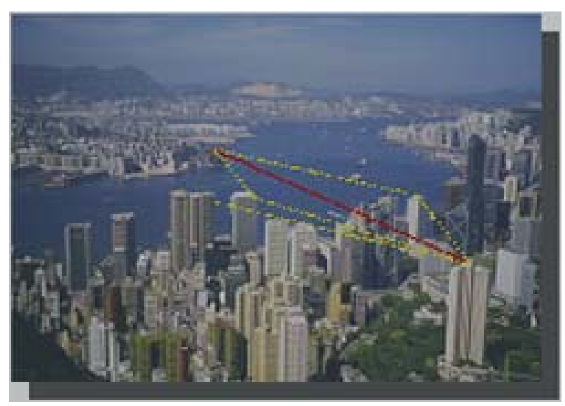
3.4.1 Fresnel Zone Benefits – Optical Line of Sight Performance

Fresnel zone encroachment is a special case of multi-path interference. When the fresnel zone is encroached by trees, buildings or the ground, reflections are caused which can become destructive multi-path interference. Since the OFDM is more tolerant of fresnel zone encroachment, reliable links will operate that otherwise could not be used, or antennas can be located in more convenient and less costly locations. For example, an antenna could be located lower on a tower, saving significant cable and antenna installation and support costs.

3.4.2 Non Line of Sight Performance

In many cases, Non Line of Sight links can be made by taking advantage of reflections off of nearby buildings, or by diffraction over the tops of trees.

In fact, many wireless links can be made even when the direct route is completely blocked by buildings or trees, i.e. entirely dependent upon reflections.



3.4.3 Extended Range

Extended range links have to deal with more significant inter-symbol interference and potential fresnel zone encroachment. Point-to-Point range exceeding 50 miles is commonplace with the Redline technology, with successful installations up to 72 Miles.

4 Beyond OFDM – Other Features of Next Generation Systems

4.1 Robust error correction

4.1.1 Dynamic Adaptive Coding at the OFDM-PHY level

We have already discussed convolutional encoding of the input data, which introduces correlations between signal samples that end up on sub-channels occurring in separate parts of the spectrum, which allows the receiver to infer the values of the signal that had ended up on fatally faded sub-carriers. However by dynamically changing the ratio of redundant code to raw data, a radio can adapt to changing link conditions. For example the Redline unit will select a more robust level of coding on a burst-by-burst basis if necessary to maintain a $1x10^{-9}$ BER.

By adapting dynamically, the unit will always select the highest data rate setting consistent with low error rates.

4.1.2 Dynamic Adaptive Modulation at the OFDM-PHY level

Similar to the coding scheme above, the modulation technique used can also be dynamically changed. The Redline unit can select between BPSK, QPSK, QAM16 and QAM64. In dynamic modulation mode, the Redline AN-50 will use the 72 Mbps QAM64 selection if link conditions permit. On a burst-by-burst basis (about 250,000 times per second), the AN-50 will adapt the modulation technique to maintain a $1x10^{-9}$ BER. Lower modulation rates also provide a higher Carrier/Interference tolerance ratio, such that that the unit can adapt to be more tolerant to certain types of co-channel interference.

4.1.3 Error correction at the RF Level

In applications using the TCP protocol, there is another level of error correction at the TCP layer. This type of correction however substantially degrades performance because the error correction process at the TCP level is relatively slow and inefficient. To avoid TCP error control, the ARQ (Automatic Repeat Request) will "hide" the error from the real TCP stack, and simulate TCP error correction but at the radio link level. The radio will retry a send-receive sequence to try to correct the error. The radio link level error correction occurs much faster, thus maximizing data rate, even in the presence of some errors. Redline goes one step further with ARQ with a unique process that causes an ARQ retry to happen at a lower more robust level of modulation / thus increasing the likelihood that a retry will be successful.

5 Desirable Radio Features in a High Capacity BWA Device

5.1 Tower Mounted Transceiver

At microwave frequencies, RF cable losses are considerable. With transmitters located indoors, the cost of purchasing and installing low loss RF cable on a tower can be thousands of dollars, and still limit output at the antenna. Quite frequently, operators still require large 4-8 foot parabolic antennas to meet their link budget requirements. Purchasing and mounting these large antennas requires careful engineering, and significant costs.

On the other hand, with a tower mounted transceiver, long range links can be completed with a light weight 1 foot square or 2 foot square panel antenna, and typically low cost and low weight RG cable. The Redline AN-50 uses standard RG 6/11 cable to support radio installations up to 500 ft up the tower.

An audible antenna-aiming tool located in the Redline transceiver is helpful during the installation process. LEDS and computer interfaces to measure antenna alignment can be difficult to manage high up on the tower.

5.2 64 QAM Support

64 QAM Support is the highest level of modulation available in license exempt wireless links today. For example the Redline AN-50 supports a 72 Mbps of coded data rate, or 54 Mbps of uncoded data, or approximately 45 Mbps average Ethernet payload. Although 64QAM will work reliably in many applications it can be susceptible to degraded link performance, or co-channel interference. This is why it is important to combine 64QAM with Dynamic Adaptive Modulation and Dynamic Adaptive Coding.

5.3 Adaptive TDD Duplexing

Time Division Duplexing is a technique in which the system transmits and receives in the same channel. For example Redline's AN-50 operates in 20 MHz bandwidth. (The alternate technique, FDD for Frequency Division Duplexing requires two pieces of spectrum usually separated by 50-100 MHz of bandwidth). TDD provides an advantage where spectrum is allocated in a contiguous block, such as the case with the unlicensed band at 5.8 GHz. With TDD there is no need for band separation, thus the entire spectrum is used efficiently.

Another key advantage with TDD is that the ratio between downstream and upstream traffic can be fixed or adaptive. Redline uses adaptive TDD which means that the unit can change the ratio of upstream to downstream traffic dynamically. Some techniques are fixed, (for example 70% downstream, 30%

upstream). Since most traffic is quite asymmetrical over short period of times, adaptive TDD can be very spectrally efficient.

TDD is particularly effective with relatively bursty data traffic, or traffic that is generally asymmetrical like Internet traffic, but it can also be used for voice.

5.4 Remote Management

Remote management features reduce the operating costs of a system, and improve availability by allowing problems to be identified proactively, and fixed rapidly. Troubleshooting and maintenance handled remotely by a skilled technician is possible through remote management tools.

Some of the features that should be considered are:

Get status information, and configure either locally or remotely via telnet or HTTP server

Update firmware revisions remotely, and return to the previous firmware revision if an upgrade fails

Get key operating statistics from the unit via telnet, HTTP or SNMP

Provision new systems, monitor status, capture statistics, store ongoing data, and report on critical operating parameters from an SNMP based Network Management System.

Redline NMS toolset, called RedAccess is a comprehensive network management system that supports full FCAPS (Fault, Configuration, Alarm, Provisioning, Security) functionality.

6 Conclusion

One of the key assets an operator has in providing fixed wireless access services is the spectrum in which the radios operate. It is imperative then that the asset is utilized in the most optimized manner possible. To this end, the Redline product not only provides superior performance, but also features key novel technologies to help maximize spectral efficiency and preserve the asset that will allow operators to maximize their return on investment.