The Advantages of TDD over FDD in Wireless Data Applications

Introduction

The convergence of voice, video and data services is the ultimate goal of many communication service providers. To achieve this goal, technologies associated with the traditional voice dominated network are replaced by newer technologies that accommodate the bandwidth demands of today’s consumer. Access schemes, such as Frequency Division Multiple Access (FDMA) and Frequency Division Duplex (FDD), were regarded as innovative technologies when first applied to the requirements of the traditional voice network. Today, however, these technologies are considered obsolete, inadequate to meet the high bandwidth demands and the dynamic nature of the current network that must deliver voice, video, Internet and data services efficiently.

Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are the two most prevalent duplexing schemes used in fixed broadband wireless networks. TDD is the more efficient scheme, however, since it does not waste bandwidth. FDD, which historically has been used in voice-only applications, supports two-way radio communication by using two distinct radio channels. Alternatively, TDD uses a single frequency to transmit signals in both the downstream and upstream directions.

In fixed wireless point-to-multipoint systems that use FDD, one frequency channel is transmitted downstream from a base station to a fixed subscriber terminal. A second frequency is used in the upstream direction and supports transmission from the customer premise to the base station. Because of the pairing of frequencies, simultaneous transmission in both directions is possible. To mitigate self-interference between upstream and downstream transmissions, a minimum amount of frequency separation must be maintained between the frequency pair.

In fixed wireless point-to-multipoint systems that use TDD, a single frequency channel is used to transmit signals in both the downstream and upstream directions.

This paper compares these two duplexing schemes with respect to their use of the available frequency spectrum, suitability for data applications and bandwidth efficiency.

Data Symmetry

Historically, the access network has been optimized for voice traffic that is symmetrical by nature. As data traffic continues to increase in the network, data rates are becoming more and more asymmetrical. Data access inherently is asymmetric, with downstream (from the network to the user) traffic outpacing upstream (from the user to the network) traffic by ratios of 4:1 in business applications and higher in residential applications.

Figure 1 illustrates the anticipated growth in data access rates for Internet service subscribers through 2005. Studies have revealed that Internet based applications dominate the traffic load and Internet connections.

Subscriber Data Access Rates

Tables 1 and 2 detail the usage of data protocols and service application in data access networks. TCP and other protocols such as FTP account for the majority of the protocol usage in data access networks. Internet access clearly dominates network connections.

Data Access Protocol Usage

Data Protocol	% Bytes	% Packets
TCP	88.78	89.8
UDP	1.38	5.93
ICMP	0.11	0.576
Other (FTP)	9.73	13.9

"Analysis of Internet Services and IP over ATM Networks," IEEE Communications Magazine, December 1999

Data Access Service Application Usage

Service Application	% Connections	% Bytes
WEB access	91.71	72.91
SMTP (mail)	4.76	0.24
ProxyWEB	0.68	0.84
FTP	0.55	12.73

FDD systems utilize channel plans that are comprised of frequencies with equal bandwidth. Since each channel has a fixed bandwidth, the channel capacity of each frequency also is fixed and equal to that of all other channels in the frequency band. This makes FDD ideal for symmetrical communication applications in which the same or similar information flows in both directions, such as voice communications.

TDD operates by toggling transmission directions over a time interval. This toggling takes place very rapidly and is imperceptible to the user. Thus, TDD can support voice and other symmetrical communication services as well as asymmetric data services. TDD also can handle a dynamic mix of both traffic types. The relative capacity of the downstream and upstream links can be altered in favor of one direction over the other. This is accomplished by giving a greater time allocation through time slots to downstream transmission intervals than upstream. This asymmetry is useful for communication processes characterized by unbalanced information flow. An obvious application for this technique is Internet access in which a user enters a short message upstream and receives large information payloads downstream.

FDD can be used for asymmetric traffic. However, in order to be spectrally efficient, the downstream and upstream channel bandwidths must be matched precisely to the asymmetry. Since Internet traffic is bursty by nature and the asymmetry is always changing, the channel bandwidth cannot be precisely set in FDD. In this respect, TDD is more efficient. Furthermore, channel bandwidths typically are set by the FCC or limited by the functionality of available equipment. As a consequence, users of FDD systems do not have the option to vary channel bandwidths dynamically in the upstream and downstream directions.

Spectrum Efficiency

Frequency spectrum is an increasingly scarce commodity. This scarcity drives the need to optimize the use of available bandwidth. FDD systems operate on the principle of paired frequencies. A channel plan is devised that is comprised of downstream and upstream channels, typically defined by the FCC, ITU, or other governing body. FDD channel plans maintain a guardband between the downstream and upstream channels. The guardband is required to avoid self-interference and, since it is unused, essentially is wasted spectrum.

In spectrum allocations such as MMDS, all designated channels are contiguous without specified transition or guardband between go and return channels. Service providers using FDD systems in these situations must create an artificial guardband in order to set aside a portion of the useable spectrum to isolate downstream and upstream frequencies. In this scheme, the spectrum is partitioned into two channel blocks that usually are separated by two vacant RF channels. At MMDS frequencies of 2.5 GHz with 6 MHz channels, this amounts to at least a 12 MHz guardband. As a consequence, two MMDS frequencies are lost. Considering that eight channels are exclusively allocated for MMDS use, the loss of two frequencies is considerable. Compared to the overall 31 channels in the MDS/ITFS/MMDS band, the loss of 2 frequencies to a guardband is about 7% of the available bandwidth. The guardband represents a lost resource and lost revenue for any Internet service provider using FDD.

One alternative is to devise a channel plan in the MMDS band to maintain a minimum transmit/receive separation. However, the licensee may not have access to enough contiguous channels to develop a frequency plan suitable for an FDD deployment.

In contrast, TDD systems require a guard time (instead of a guardband) between transmit and receive streams. The TX/RX Transition Gap (TTG) is a gap between downstream transmission and the upstream transmission. This gap allows time for the base station to switch from transmit mode to receive mode and subscribers to switch from receive mode to transmit mode. During this gap, the base station and subscriber are not transmitting modulated data but are simply allowing the base station transmitter carrier to ramp down, the TX /RX antenna switch to actuate, and the base station receiver section to activate. The TTG has a variable duration that is an integer number of physical time slots (PS). The TTG starts on a PS boundary.

The TTG is equal to following value:

TTG (in seconds) = 2 x (maximum link distance in Km) / (speed of light) + modem TX/RX transition

TTG (in PS) = TTG (seconds) / (4 x symbol rate)

Air Interface Frame with Transition Gap

As an example, if the maximum link distance is 10Km, the speed of light is 3.0e+8 M/sec, and the TX/RX transition is 1 µsec, the TTG is given as:

TTG = 2 x (10 km / 3e+8) + 1 µsec = 67 µsec

Or

TTG = 67 µsec / (4*(1/5 MHz)) = 84 PS

Hence, only 3.4% of the available bandwidth is lost to the TX/RX guardband as compared to FDD.

Hardware Complexity

In FDD systems, two RF channels are in continuous operation at each site; the transmitter operates simultaneously with the receiver. As the downstream and upstream channels typically are close to one another, the transmit signal can overpower the sensitive receiver tuned to the nearby channel. To mitigate self-interference, FDD systems require special filters called duplexers along with careful design of mechanical and electrical shielding to prevent such overload.

The cost of duplexers and implementation of RF shielding increases as the guardband or separation of the two channels decreases. With TDD systems, duplexers and isolation techniques are unnecessary since transmit and receive channels within a sector never are active simultaneously and cannot interfere with each other. Consequently, TDD hardware is less complex and less expensive.

Frequency Planning

In TDD systems, the transceiver switches between transmit and receive modes based on units of time within the same channel. In many countries, block frequency allocations are made to service providers to provide maximum flexibility in deploying services. In many cases, these allocations are made without regard for the spacing required between transmit and receive frequencies for FDD equipment. An example of this is the MMDS/ITFS or LMDS frequency bands in the United States. Thus, the frequencies allocated for broadband services can become fragmented and non-uniform when FDD rules are applied. Without careful planning, the result can be wasted spectrum. Because of the need for a guardband between the transmit and receive channels, as discussed earlier, some service providers may not have enough bandwidth to provide FDD-based services. TDD systems offer a tremendous advantage over FDD in this respect since they can be deployed with as little as one channel of available TDD spectrum. This eliminates the paired channel allocations required by FDD and allows operators to take full advantage of spectrum allocations that are contiguous, non-contiguous, or small. This makes TDD systems particularly attractive to MMDS operators who have access to only certain MMDS or ITFS channels.

Since the UNII band is unlicensed, the potential for interference is high. Furthermore, MMDS licensees must be concerned with intra-system interference as well as with legacy MDS and ITFS systems. Both TDD and FDD require proper frequency planning for interference mitigation. However, FDD systems require clearing two frequencies: one uplink and one downlink. TDD is concerned only with finding one clear frequency, which simplifies frequency coordination. Both FDD and TDD systems must consider base-base and subscriber-subscriber interference in addition to base-subscriber and subscriber-base interference paths. TDD frequency planning is somewhat different than the FDD approach, yet both require the use of cell planning tools to properly analyze frequency interference.

Dynamic Bandwidth Allocation

One important feature of TDD systems is the recognized, quantifiable performance advantages over FDD systems when transporting bursty data such as Internet traffic. Voice traffic is constant and predictable, whereas data traffic is variable and unpredictable. Because TDD operates in the time domain, unpredictable data that vary in time can be transported more efficiently. Raze Technologies' TDD implementation can dynamically vary the amount of channel capacity allocated to upstream and downstream communications, up to the total capacity of the channel. In other words, it "borrows" time from the transmit direction to increase the return direction as necessary, or vice versa.

The total quantity of bits downloaded over a long time period is the same for both FDD and TDD. However, their delay performance is not. The user does not want a long, time-averaged rate. Instead, the user wants an instantaneous peak rate so that data downloads occur as quickly as possible.

As an example, consider a system that has 20 Mbps capacity available. Disregarding the guardband requirement of FDD implementation, assume that the downstream/upstream ratio is 4:1. This means that 4 Mbps data rate is allocated to the upstream channel while 16 Mbps data rate is allocated to the downstream channel. This is shown in Figure 3.

Initial Capacity Allocations

Assume that new traffic demands require the allocation be changed to a downstream/upstream ratio of 9:1. This means that 2 Mbps data rate needs to be allocated to the upstream and the remaining 18 Mbps data rate needs to be allocated to the downstream traffic. TDD easily adapts to the new demand and allocates capacity as shown in Figure 4. However, FDD cannot easily adapt to this demand. Instead it continues to use 4 Mbps for the upstream traffic and 16 Mbps for the downstream traffic. As a result, 2 Mbps is wasted in the upstream direction, with a shortage of 2 Mbps in the downstream direction. Thus, TDD can dynamically "borrow" bandwidth instantaneously from one direction, while FDD cannot dynamically borrow frequency bandwidth.

Dynamic Bandwidth Demands

To further illustrate the spectrum efficiency of TDD over FDD, consider the Raze SkyFire system operating in the MMDS band. The SkyFire system is capable of dynamically allocating time slots as well as modulation schemes. In the downstream direction, 16- and 64-QAM modulations are used, while in the upstream direction 16-QAM and QPSK are used. Subscribers located closer to the base station will use the higher QAM rates. A single 6 MHz MMDS channel is used.

A comparable FDD system also is capable of using 16- and 64-QAM modulation schemes in the downstream direction but only QPSK in the upstream direction. A pair of MMDS channels is used in the FDD case, for a total of 12 MHz of bandwidth.

Figure 5 shows how TDD spectrum efficiency increases as the downlink to uplink ratio increases, which is typical for Internet applications. FDD spectrum efficiency decreases since the decrease in upstream data results in an over allocation of bandwidth, hence a decrease in the bits per hertz utilized.

Spectrum Efficiency as a Function of Downlink to Uplink Ratio

During a typical day, the upstream/downstream traffic ratio will vary as users come and go and as user groups (business, residential, universities) hit their peak time of usage. This ability to allocate bandwidth dynamically, or "on demand," permits the service provider using TDD to always have the optimal traffic split and provide different grades of service to users within the same sector. Subscribers will be provided bandwidth according to their traffic needs, QoS and Service Level Agreements.

Conclusions

The above discussion has highlighted the advantages of TDD over FDD. These advantages can be summarized as follows:

- FDD is an older scheme that was best suited for applications, such as voice, that generate symmetric traffic, while TDD is best suited for bursty, asymmetric traffic, such as Internet or other datacentric services.
- In TDD, both the transmitter and receiver operate on the same frequency but at different times. Therefore, TDD systems reuse the filters, mixers, frequency sources and synthesizers, thereby eliminating the complexity and costs associated with isolating the transmit antenna and the receive antenna. An FDD system uses a duplexer and/or two antennas that require spatial separation and, therefore, cannot reuse the resources. The result is more costly hardware.
- TDD utilizes the spectrum more efficiently than FDD. FDD cannot be used in environments where the service provider does not have enough bandwidth to provide the required guardband between transmit and receive channels.
- TDD is more flexible than FDD in meeting the need to dynamically reconfigure the allocated upstream and downstream bandwidth in response to customer needs.
- TDD allows interference mitigation via proper frequency planning. TDD requires only one interference-free channel compared with FDD, which requires two interference-free channels.

In summary, TDD is a more desirable duplexing technology that allows system operators to receive the most from their investment in spectrum and telecom equipment, while meeting the needs of each individual customer.