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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, including Third Generation Wireless Systems	)	ET Docket No. 00-258
	)	
Amendment of Section 2.106 of the Commission's Rules to Allocate Spectrum at 2 GHz for Use By the Mobile-Satellite Service	)	ET Docket No. 95-18
	)	
The Establishment of Policies and Service Rules for the Mobile-Satellite Service in the 2 GHz Band	)	IB Docket No. 99-81
	)	
Petition for Rule Making of the Wireless Information Networks Forum Concerning the Unlicensed Personal Communications Service	)	RM-9498
	)	
Petition for Rule Making of UTStarcom, Inc., Concerning the Unlicensed Personal Communications Service	)	RM-10024

REPLY COMMENTS OF THE TDD COALITION

The TDD Coalition[1] ("Coalition") hereby submits the following reply comments to the Further Notice of Proposed Rulemaking ("Further Notice") in the above-captioned matter.

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[1] The TDD Coalition is an industry consortium organized for the purpose of promoting TDD technology and working with regulatory bodies around the world to develop implementation guidelines that allow TDD deployments and insure harmonious coexistence of TDD with other duplexing systems. The member companies of the TDD Coalition are: Aperto Networks; ArrayComm, Inc.; BeamReach Networks, Inc.; CALY Networks; Clearwire Technologies; Harris Corporation; Interdigital Communications Corp.; IP Wireless; LinkAir Communications; Malibu Networks; Navini Networks; PointRed Technologies; Radiant Network; Raze Technologies, Inc.; and Wavion, Ltd. The Coalition attaches, for the record, a copy of its White Paper titled "The Advantages and Benefits of TDD Broadband Wireless Access Systems" (September 2001) as Appendix A.

1. **Introduction**

The Coalition is pleased to note that the majority of the commenters addressing time division duplexing ("TDD") support the notion that spectrum allocations for new advanced wireless services, including third generation wireless ("3G"), should expressly accommodate TDD. It is disappointing, however, that the comments expressing support for such an allocation represented only a small fraction of the larger body of comments filed in this proceeding. The Coalition believes that the lack of attention to technological neutrality in the comments is an unfortunate result of the Commission's failure to emphasize this critical issue in its Further Notice. As the Coalition noted in its comments, a technology-neutral allocation that allows licensees to provide both TDD and frequency division duplexing ("FDD") would help to promote the efficient use of spectrum and bring enormous benefits to consumers, operators and manufacturers. It is crucial that the Commission revive its agenda for a technology-neutral allocation of spectrum to new advanced wireless services.

A small number of commenters have made arguments against the allocation of spectrum in a manner allowing for the use of TDD technology. While those commenters focused on just one portion of the radio frequency spectrum under consideration, one commenter made broader statements taking aim at TDD technology as a general matter. As explained below, those statements are unsupported. The Commission should recognize the value of a technology-neutral allocation that allows TDD and FDD to compete.

Finally, the Coalition is encouraged by the broad support among commenters — with one exception — for a spectrum allocation that is harmonized with international allocations for similar services. The Coalition agrees and reiterates its support for a harmonized approach to spectrum allocation.

2. The Commission Should Pursue a Technology-Neutral Spectrum Allocation Policy

The benefits of a technology-neutral spectrum allocation policy that would permit both TDD and FDD to compete are clear. TDD, which is designed to adapt to time-varying asymmetrical uplink and downlink traffic, is particularly well suited for the data-heavy transmissions involved in 3G and other advanced wireless communications services. As such, this technology, if given the chance, would be a vigorous competitor and a beneficial alternative to FDD, which cannot match time-varying asymmetry. What is needed is a spectrum allocation policy that departs from the paired allocations that serve to skew the playing field to the advantage of FDD, but rather supports paired and unpaired allocations with technology-neutral rules that define coexistence parameters such as power limits, adjacent channel interference, and spectral masks.

Unfortunately, the comments submitted in response to the Commission's Further Notice by and large fail to address technological neutrality as a guiding principle in the allocation of spectrum for new advanced wireless communications services. This is not a surprising development. As the Coalition noted in its comments, the Further Notice failed to emphasize technological neutrality despite the beginnings of a promising discourse on the subject in the Notice of Proposed Rulemaking ("NPRM").[2] Although the Further Notice contained some discussion of allocations that might permit the use of

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[2] Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, including Third Generation Wireless Systems, Notice of Proposed Rule Making and Order, 16 FCC Rcd 596, 608 (¶ 29) (2000) ("NPRM").

unpaired frequencies, no mention was made of a scenario under which bidders could acquire unpaired spectrum only.[3]

Despite the Commission's apparent willingness to let technological neutrality wither on the vine, a number of commenters advocate a spectrum allocation policy that gives different technologies a possibility to compete. For example, Cingular proposes a reallocation of the 1915-1925 MHz band for TDD, retaining the 5 MHz on either side as guard bands, and a reallocation of the 2010-2025 MHz band either for TDD or for relocation of incumbents from other bands being cleared for advanced wireless services.[4] Siemens and Orange Group propose explicit allocations for both FDD (two 5 MHz blocks at 1920-1930 MHz paired with two 5 MHz blocks at 2110-2120 MHz) and TDD (two 5 MHz blocks at 1910-1920 MHz).[5] Ericsson, while stopping short of advocating explicit designations for TDD or FDD, states that the 1910-1930 MHz and 2385-2400 MHz bands "could be suitable for advanced mobile wireless services, primarily those services that can take advantage of unpaired spectrum technologies."[6]

While the particular frequency allocations advanced by those commenters may or may not represent the optimal means of accommodating both TDD and FDD, the Commission should come away with a broader lesson: there is growing recognition within the industry of the importance of technological neutrality.[7]

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[3] See Further Notice at ¶¶ 42-44.

[4] Comments of Cingular Wireless LLC at 11-13.

[5] Comments of Siemens Corp. at 2; Comments of Orange Group at 4.

[6] Comments of Ericsson at 7.

[7] Technological neutrality also finds support within the government, as evidenced in the recent remarks by Nancy J. Victory, Assistant Secretary for Communications and Information, U.S. Department

3. **The Commission Should Reject NEC's Unsupported Assertions About TDD**

NEC America, Inc. ("NEC"), in arguing against the reallocation of the 1910-1930 MHz band for new advanced wireless services, levels a broad attack against the use of TDD for that band. Specifically, NEC argues that the limitation of that band to TDD use would make it "inherently less valuable in the marketplace" and that "the lack of a ready market for TDD would have a significant, negative impact on the development of equipment for the band."[8] The Commission should reject these arguments, which find no support in NEC's comments or the facts.

NEC fails to provide a factual basis for its conclusions about TDD. This is not surprising: there is none. Far from reducing the value of spectrum, the use of TDD technology promotes greater efficiency in the use of spectrum and provides greater flexibility with respect to multiple frequency band deployments. TDD channels support directional multiplexing in which the entire channel capacity can be made available to both uplink and downlink, allowing for the efficient use of an operator's entire bandwidth. Additionally, manufacturing costs are reduced as a result of the transferal of the duplexing cost/complexity to digital baseband (MAC ASIC) from RF/millimeter-wave (duplexer). Sparing and inventory costs also come about as a result of eliminating the pairing characteristic associated with FDD radio front-ends. Finally, TDD systems

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of Commerce, before the National Summit on Broadband Deployment on October 25, 2001 ("Government's role, therefore, should be to facilitate the deployment of new technologies by removing any unnecessary roadblocks to that deployment . . . [W]here possible, competition should be promoted using a technology-neutral paradigm.")

8 Comments of NEC America, Inc. at 19-20.

allow intelligent management of scarce radio resources through the use of innovative advanced signal processing schemes.[9]

These facts plainly fly in the face of NEC's bold assertion that TDD lacks a "ready market." Indeed, as described above, several commenters argue forcefully for spectrum allocations that explicitly provide for TDD systems, a fact that demonstrates TDD's potential as a viable alternative to FDD. The viability of TDD has similarly been accorded recognition at the international level, as evidenced by the designation of the 1900-1920 MHz and 2010-2025 MHz bands for UMTS TDD in the WRC-2000 band plan for IMT-2000 services. Thus, the Commission should reject NEC's arguments against the designation of frequencies for this useful and value-creating technology.

4. Global Harmonization Should Play a Decisive Role in Spectrum Allocations

The Coalition notes that several commenting parties made passing reference to the importance of harmonizing spectrum allocations for 3G and other advanced wireless services with those for similar services around the world. However, the Coalition wishes to emphasize that global harmonization should play a decisive role in determining appropriate spectrum allocations for these services.[10]

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9 See Appendix A.

10 The lone exception to the broad-based expression of support for harmonization is Lockheed-Martin Corp., whose comments assert that "the emphasis on the need for global harmonization of domestic 3G spectrum has been misplaced" and "has unnecessarily restricted the exploration of possible options for domestic spectrum allocations for 3G." Comments of Lockheed-Martin Corp. at 2. As the Coalition discussed in its comments, harmonization brings enormous benefits in the form of lower costs, more rapid innovation, improved roaming and customer convenience, and accelerated market growth. Comments of the TDD Coalition at 4. Emphasis on global harmonization is therefore not "misplaced."

5. Conclusion

For the foregoing reasons, the TDD Coalition respectfully requests that the Commission resume its pursuit of a technology-neutral band plan for new advanced wireless services, with defined parameters for power limits, adjacent channel interference, and spectral masks.

Respectfully submitted,

TDD COALITION

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Dated: November 8, 2001

APPENDIX A

A TDD Coalition White Paper

The Advantages and Benefits of TDD Broadband Wireless Access Systems

Presented by:

The TDD Coalition

September 2001

1. Introduction

Time Division Duplexing (TDD) is not a new technology. However, a new generation of wireless systems designed around TDD are revolutionizing emerging segments of the telecommunications marketplace, areas such as broadband wireless access, 2G and 3G wireless mobile systems, and wireless LANs. Previous generations of wireless systems such as the widely deployed cellular network have most recently implemented Frequency Division Duplexing (FDD) schemes that require one-way traffic in each of the allocated (paired) bands, and FDD-based standards. Since most wireless communications systems have been implemented using FDD schemes, there has been a tendency in the wireless communications industry to seek and among spectrum regulators to allocate solely paired spectrum for FDD-based systems. Now, through growing adoption of TDD, next generation systems promising more effective use of spectrum, higher performance, and lower cost are now being brought to market. With minimal safeguards, TDD can easily coexist with other duplexing schemes, enabling operators to consider new systems with the advanced capabilities that TDD can provide.

From a purely technical vantage point, the benefits of TDD have become apparent to many of the innovative companies developing product for broadband wireless access. To date, FDD has been a more broadly deployed duplexing method due largely to its use in cellular telephony. As a result, some allocation decisions and other regulations that have either prohibited or hindered the deployment of duplexing alternatives, such as TDD. In order to combat this trend, technical innovators who see advantages in implementing TDD must aggressively manage market expectations, market the advantages of TDD, and change attitudes about duplexing schemes. In order to promote TDD and its implementation, a group of companies that support TDD has formed a new industry group called the TDD Coalition. The goal of the Coalition is to promote the benefits and advantages of TDD. Information about the TDD Coalition and its members is provided at the end of this paper.

2. What is TDD?

In two-way communications systems, separate channels are required to convey information in each direction, for example from a base station to a cellular user, and vice-versa. With wireless systems, this is accomplished by separating channels either in time, in frequency, or in both time and frequency. Creating directional channels in this fashion is called "duplexing."

Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are the two most prevalent duplexing schemes used in fixed broadband wireless networks. FDD, which historically has been used in voice-only applications, supports two-way radio communication by using two distinct radio channels. Alternatively, TDD allows for 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 up and downstream transmissions, a minimum amount of frequency separation must be maintained between the frequency pair.

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

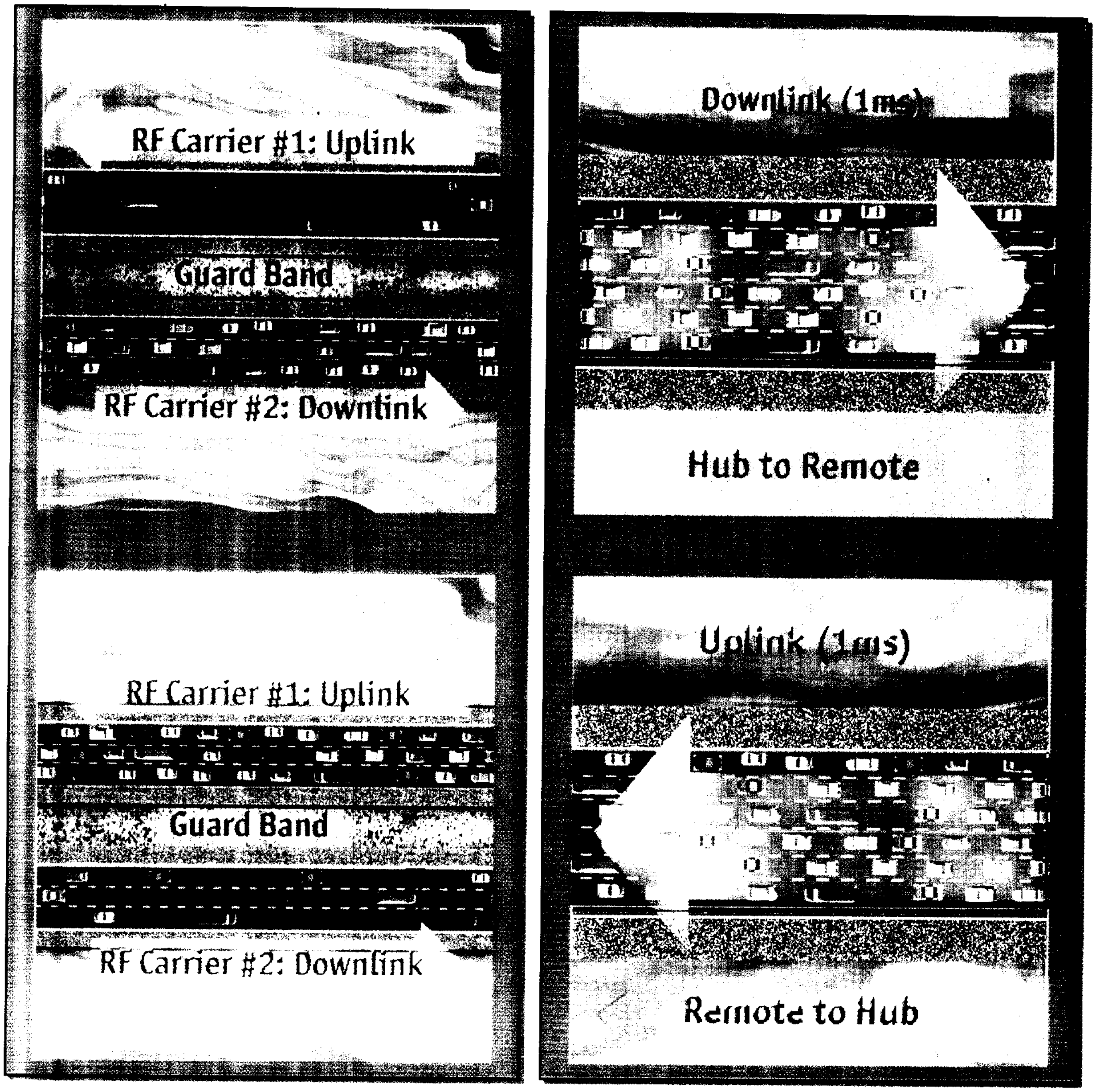

Figure 1. FDD is like a divided highway. TDD is like a one-way highway that changes direction.

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

3. TDD Deployments

TDD is a technically proven, efficient and cost effective method of performing duplex communication. Two examples of TDD systems that have been deployed are Digital Enhanced Cordless Telecommunications (DECT) and Personal Handyphone System (PHS). Both were originally designed to provide low-mobility, high quality voice (32 kbps ADPCM) service in the 1900 MHz band. They clearly demonstrate the viability of TDD as a duplexing method in communications systems.

Yet, the benefits offered by TDD are more apparent when applied to today's emerging broadband wireless access (BWA) systems. By serving the voice and data (bursty in nature) needs of small to medium sized businesses, emerging BWA systems will provide a set of services fundamentally distinct from those offered by DECT and PHS. Because of this, TDD BWA systems can exploit TDD's unique capabilities in a way that DECT and PHS have not.

4. Advantages of TDD

4.1. Use in Data Services

One consideration in deciding on a duplexing scheme is the nature of the traffic being carried. FDD can adequately handle traffic that has relatively constant bandwidth requirements in both communication directions: uplink and downlink. However, TDD better handles time-varying uplink/downlink traffic because the nature of the duplex scheme matches the nature of the traffic.

TDD is particularly advantageous for data delivery. Unlike voice services, for example, where symmetric uplink and downlink resources are generally appropriate, the uplink and downlink traffic in a data application can be highly asymmetric. The degree of asymmetry can be time-varying, as well. A residential consumer surfing the web could be generating twenty times as much downlink data as uplink data; a single mouse click could easily result in many large image files being transferred to his machine. When uploading files to Napster, for example, or images to his website, that same consumer could reverse the asymmetry of his data, to be twenty times greater on the uplink. And, while telecommuting, a more balanced data flow could result when collaborating or videoconferencing with colleagues. The advantage of TDD in this regard is that the assignment of uplink and downlink traffic resources can be adapted to the users' needs by varying the relative fractions of time dedicated for uplink and downlink traffic, making the best use of the operator's spectral resources and providing the highest level of user satisfaction.

TDD employs the dimension of time in order to carry duplex traffic on one physical channel with bandwidth X (X being a value somewhat less than the actual physical capacity of the channel). FDD employs the dimension of frequency, or more particularly bandwidth, to provide two physically separate channels (one dedicated to uplink, the other to downlink), with total bandwidth X, for carrying duplex traffic. For practical reasons, once bandwidth allocations have been made for the two FDD channels, these are assumed to be static partitions (an immovable boundary in frequency/bandwidth). The analogous TDD partition is a temporal boundary between uplink time and downlink time. This time boundary, unlike the FDD case, is inherently flexible, and can respond to time-varying uplink/downlink bandwidth demands. This allows a time-shared "directional multiplexing" of the TDD common channel between uplink and downlink traffic that is not possible with other schemes. It is well known in telephony that multiple users can share a common resource more efficiently than multiple partitioned resources.

Uplink and downlink traffic may or may not be generally asymmetric, depending on the types of users being served, whether there are Web servers at the remote locations, etc. However, if it is granted that FDD channels can be sized asymmetrically, then asymmetry itself is not an argument for TDD over FDD. Rather, an asymmetry that varies with time is the argument for TDD. The ratio of uplink/downlink (push/pull) traffic loads may change over time scales of milliseconds to months, ranging from a 10 ms peak in the downlink traffic ending to the gradual, months-long evolution of remote subscriber configurations. On any time scale, these fluctuations would be difficult to handle with FDD's static uplink/downlink bandwidth partitions.

While a user is downloading information, he/she wants the quickest response possible. Then he takes his time to digest the information before taking further action. In other words, a period of peak activity is followed by a period of low or no activity. This means that the user has a low average download rate, as averaged over several "download-digest-download-digest" cycles. Most users would not want this "averaged" rate as their download speed. Properly designed broadband systems allocate capacity to specific users "instantly," and given sufficiently large numbers of users, take advantage of statistical multiplexing to serve each user adequately with a fraction of the bandwidth needed to handle the peak rate of all users simultaneously, with capacity being allocated on demand rather than on a fixed basis.

A typical user will expect to have an instantaneous high bandwidth available, delivered by his access mechanism, but only occasionally. For example, he might expect a large document to be delivered very quickly so that he can start reading and digesting its contents. However, the period over which he is looking at the information in local storage means that the average bandwidth required to deliver a good service is low, even though the instantaneous bandwidth required is high. In this example, the average bandwidth required is constrained by the user's ability to read and assimilate information, but the instantaneous bandwidth required is dictated by the user's patience in waiting for complete documents to be delivered. The above implies a quality-of-service (QoS) issue that may not always be generally recognized or specified: the download rate experienced by the user. This is referred to as the "download QoS".

It is interesting to note how time and bandwidth are used differently by the two systems. In this particular TDD example, downloads consume 2/3 of the time, with uploads consuming the remaining 1/3 (on average), and each direction has an instantaneous, available capacity of X Mbps. By contrast, the FDD system (at its most efficient) has lower bandwidth traffic flowing almost continually (in time) in both directions, at or near the respective capacities in both directions. Since uplink and downlink traffic is bursty, the FDD system must buffer traffic and respond to bandwidth demands in a time-averaged fashion (seen by the user as a slower rate of service).

4.2. Network Deployments

Deploying a Point to Multipoint radio across multiple frequency bands involves more RF engineering design for FDD as compared to TDD systems. A unique transceiver and duplexer design is required for each band in support of various T/R spacing and bandpass widths. These parameters affect the choice of first intermediate frequency (IF) and main local oscillator (LO) circuit architectures, which will change depending upon the operating band. As a result, product development and planning becomes more difficult and less efficient. Also, the time and effort required for network planning is exacerbated.

4.3. Design Implementation

Because FDD systems require two channels for communication [one channel for the downlink (or hub to remote) and a second for the uplink (or remote to hub)], sufficient isolation between these transmissions is required for low Bit Error Rate (BER) performance. This isolation can be achieved by any of the following:

a) a duplexer to allow both transmitter and receiver to connect to a common antenna;
b) separate antennas for transmit and receive with no duplexer;
c) Use of a dual polarized antenna with opposite polarizations assigned to transmit and receive.

In option a), sufficient frequency separation (duplexer spacing) is required for cost effective duplexer implementation. In general, duplexer cost is inversely proportional to the size of the frequency separation. The lower practical limit of this separation is about 1 percent of the carrier operating frequency. By way of comparison, FDD air interfaces for cellular systems have separations of 2 percent or more. The 31 GHz band (referred to as the LMDS B block in the USA), which consists of two 75-MHz channels separated by only 150 MHz, represents a frequency separation of approximately 0.5 percent (.01 x 31GHz= 310 MHz) and represents an expensive duplexer implementation. In a typical 2.5 GHz (MMDS in the USA) FDD implementation, the guardband would cost an operator between 7 to 25% of his available spectrum.

In option b), although the guardband can be eliminated, use of two antennas may not be desirable at some sites. One of the key benefits of deploying point-to multipoint networks is the operator's ability to amortize hub costs across several remote sites. Furthermore, the cost of an additional antenna at the remote adds directly to the per link cost.

Option c) represents a hybrid approach that uses a single antenna, but requires two oppositely polarized feeds. Duplexer filtering is required in addition to the dual polarized antenna to achieve the necessary isolation that the dual polarized antenna alone cannot provide. Although the duplexer cost is reduced, it is offset somewhat by the cost of the dual polarized antenna feed.

TDD systems require only a simple two-way switch to achieve transmit/receive isolation, thereby eliminating the need for guardbands and duplexers, and the associated radio system mechanicals required for the above three options. TDD systems require a time domain guardband, or guardtime, between the transmit and receive links. For the cell sizes under consideration for LMDS or equivalent European systems, this is approximately 1.5 percent of the operating bandwidth and does not amount to a significant loss of capacity. In the LMDS A block, which is 850 MHz (27.50 to 28.35 GHZ), 1.5 percent of the bandwidth (.015 x 850 MHz) is about 13 MHz. In an FDD system, the required guardband, at the lower practical limit of 1 percent of the operating frequency as described above, would amount to 280 MHz (.01 x 28 GHz).

In spectrum allocations where no transition or guardband is specified, FDD manufacturers must create artificial guardbands wherein a portion of the spectrum is used for a duplexer guardband. In this scheme, the spectrum is partitioned into multiple sub-bands, separated by at least 1% of the operating frequency as described above. Although FDD radios can be configured to utilize the guardband, radios must be matched or paired, thereby preventing complete coverage with a single radio and increasing sparing and inventory overhead as a result.

TDD systems are more flexible in that they can be deployed with as little as one unpaired channel of available spectrum. The FDD problems of T/R pairing and spacing are eliminated, enabling the operator to deploy with contiguous or non-contiguous spectral blocks. Sparing and inventory tracking is simplified as the TDD radio can operate over the entire band of interest.

5. Spectral Efficiency: TDD vs. FDD

Frequency spectrum is an increasingly scarce commodity. This scarcity drives the need to optimize the use of the 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, CEPT, 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 is essentially wasted spectrum since it is unused.

In spectrum allocations such as MMDS, all of the designated channels are contiguous, and no transition or guardband between go and return channels is specified. Service providers using FDD systems in these situations must create an artificial guardband. This guardband sets 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 are separated by generally 2 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, 2 MMDS frequencies are lost. Considering that there are only 8 channels exclusively allocated for MMDS use, the loss of 2 frequencies is a considerable loss of resource. 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.

A channel plan could be devised in the MMDS band that maintains a minimum transmit/receive separation. However, it is a false assumption that the licensee has access to enough contiguous channels that a frequency plan suitable for an FDD deployment can be devised.

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 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)

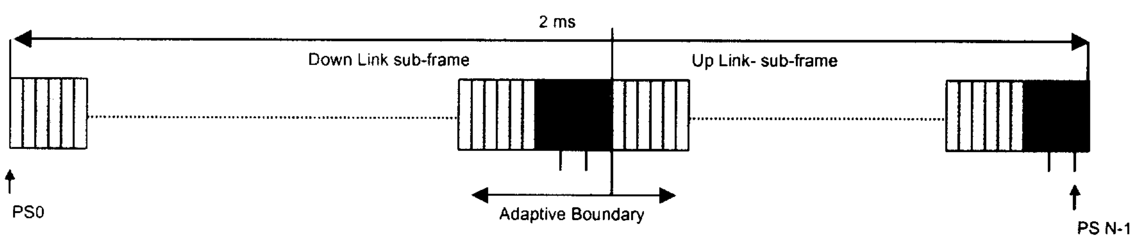

Figure 3: Air Interface Frame with Transition Gap

As an example, if the maximum link distance is 10 km, 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 guard band as compared to FDD.

6. Advanced System Innovations Using in TDD

Members of the TDD Coalition have developed important technical innovation through the implementation of TDD.

System advantages can be obtained from the use of reciprocal channels - a unique feature of TDD systems. Channel reciprocity for single carrier frequency shared by uplink and downlink allows an easier access to channel-state information for advanced signal processing techniques. For instance, channel reciprocity ensures that the fading on the uplink and downlink are highly correlated. Since the channel characteristics are same in both directions, any signal processing resources for doing space/time/equalization/frequency processing can be shared between the transmitter and receiver. Hence, TDD is a uniquely suited technology for advanced signal processing in the areas of open-loop power control, novel multi-path and antenna combining, and time-space processing techniques, with a lower cost adder.

For example, adaptive antenna arrays can be added by implementing advanced signal processing at the basestation and sharing the channel weighting information with the subscriber units. This allows the spectral efficiency of the system to be increased by an order of magnitude without increasing the CPE cost. Another example is mesh networks. These innovative systems are enable by the implementation of TDD. The network and frequency planning in an FDD mesh network system would be impossible to develop.

Another area of innovation is in media access control (MAC). The TDD operation allows for highly dynamic and various configurations of physical layer time frame. TDD systems have a much higher flexibility to handle the dynamic up/down traffic, since the boundary between uplink and downlink duty cycle could be adaptively adjusted to accommodate the service requirements. Dynamic TDD systems are far more bandwidth efficient than the traditional FDD systems for the future data-centric multimedia traffic. By implementing intelligent ("channel-aware") media access control (MAC) protocols and use of the superior architecture provided by TDD, throughput multiplication, statistical multiplexing gain, and reduction of packet delays can be achieved.

7. TDD in Broadband Wireless Access Networks

As the balance of network traffic shifts from predominantly voice to data and point-to-multipoint networks begin to deploy, attention is being focused on the underlying airlink technologies on which these networks are based. In much the same way that the cellular industry debated CDMA vs. TDMA, the wireless broadband industry is now debating the merits of FDD vs. TDD in broadband wireless access networks. In the fixed wireless industry, FDD, frequency division duplexing, is the legacy airlink protocol that is used in point-to-point networks deployed around the world. FDD was originally established for use in point-to-point networks for transporting analog voice traffic, which is largely symmetrical and predictable. TDD, on the other hand, is being used in the design of broadband wireless access networks to transport digital data, which is asymmetrical and unpredictable.

Even though TDD is well suited for carrying data, it can carry voice as well with good quality of service (QoS) and minimal latency. TDD systems can transport quasi-continuous or bursty traffic or a mix of both indistinctively.

8. Summary

TDD has several distinct advantages in Broadband Wireless Access systems. This paper has highlighted these advantages with respect to support for data-centric services, deployment, radio simplification, and frequency planning.

TDD provides the service provider with a hedge against the uncertainty associated with the asymmetry of Internet traffic. A TDD system allows efficient use of an operator's entire bandwidth, such that quality of service is improved and revenue is enhanced through more efficient network over-subscription.

TDD channels support directional multiplexing in which the entire channel capacity can be made available to both uplink and downlink. Dynamic payload distribution can be efficiently supported through software control over intervals as short as 10 ms. The result is a statistical gain over FDD systems in the context of over-subscribed channels and bursty data traffic.

Manufacturing costs are reduced as a consequence of the transferal of the duplexing cost/complexity to digital baseband (MAC ASIC) from RF/millimeter-wave (duplexer). Sparing and inventory costs also come about as a result of eliminating the pairing characteristic associated with FDD radio front-ends.

TDD systems offer service providers greater flexibility with respect to multiple frequency band deployments. In many of the spectrum allocations licensed worldwide, the FDD designation is ambiguous or simply does not exist. FDD radio architectures are strongly influenced by FDD band plans. Lack of a clear FDD designation will slow FDD radio developments as a result. Also, TDD allows frequency re-use, providing greater efficiency in the use of spectrum.

TDD systems can be deployed without a designated band plan. TDD deployments are possible within contiguous or paired channel blocks. The common radio architecture simplifies sparing and eliminates kitting thereby reducing operating costs for the multi-band operator.

TDD systems allow intelligent management of scarce radio resources through employing innovative advanced signal processing schemes. TDD is an established technology driven by the realities of today's market demands and the deployment of dynamic and scalable broadband wireless access networks.

About the TDD Coalition:

The TDD Coalition was created to promote the broad use of TDD technology for wireless broadband products. The group will endeavor to educate the industry and policy-makers about TDD technology, and its advantages for global broadband wireless development.

The members of the TDD Coalition are a broad range of innovative companies that have implemented TDD-based systems. Although the companies may implement TDD in different ways, they all have used TDD to create products with unique advantages. Some have used TDD to use spectrum more efficiently, some have used TDD to develop lower cost products, and others have used TDD to create higher performance products. A key goal of the TDD Coalition is to promote the benefits and advantages of TDD, and to share information about how TDD can coexist with other forms of duplexing technologies.

One of the most important functions of the Coalition is its work to inform national and international regulatory bodies. By adopting technically sound, competitively neutral service rules, regulators will allow economical deployment of TDD technology for broadband wireless access. In many cases, only small considerations are needed to allow an efficient implementation of a TDD-based solution. With regulatory bodies around the world, the TDD Coalition is working to develop implementation guidelines that will allow TDD deployments and insure harmonious coexistence of TDD with other duplexing systems. As an extension of these efforts, the Coalition works to support TDD within global, regional and national standard organizations.

The member companies of the TDD Coalition are:

Aperto Networks	ArrayComm, Inc.	BeamReach Networks Inc
CALY Networks	Clearwire Technologies	Harris Corporation
InterDigital Communications	IP Wireless	LinkAir Communications
Malibu Networks	Navini Networks	PointRed Technologies
Radiant Network	Raze Technologies, Inc.	Wavion Ltd.