IDA Consultation Paper dated 2nd April 2004

DEPLOYMENT OF WIRELESS BROADBAND TECHNOLOGIES IN SINGAPORE

To :

Mr Andrew Haire
Senior Director, (Policy & Competition Development)
Infocomm Development Authority of Singapore,
8, Temasek Boulevard,
14-00 Suntec Tower Three,
SINGAPORE 038988

Please find below the views and comments of :

a) **ArrayComm Inc.,**
2480 N.First Street, Suite 200,
San Jose,
CA 95131-1014
USA

(Contact : Mr Vivek Gupta)

b) **Kyocera Corporation**
Yokohama Office 2-1-1 Kagahara
Tsuzuki-ku
Yokohama-City
Kanagawa 224-8502
JAPAN

(Contact : Mr Shoichi Nakano)

c) **ArrayAsia Pte Ltd**
9, Temasek Boulevard
15-03 Suntec Tower Two
SINGAPORE 038989

(Contact : Mr Malcolm de C Richards)

Reply Comments on IDA Paper

9 INVITATION FOR COMMENTS

9.1 IDA would like to seek the views and comments from the industry and members of the public on the issues and proposals raised in this consultation. This will allow IDA to have a better understanding of the issues and the different needs and requirements of the different interested parties. The questions are listed below:

(a) View and comments on the potential of and benefits arising from the deployment of wireless broadband technologies, the likely services/applications to be deployed and the potential demand from businesses and consumers.

[ArrayComm Inc]

Thirty years ago, people started making telephone calls 'on the move' rather than being tied to a phone line. They were freed to communicate wherever they wanted – anytime, anywhere – they were un-tethered and they were free to move. This simple concept – freedom to communicate anytime, anywhere – has since created new industries, new technologies, and new businesses all focused on the opportunities arising from provision and use of wireless voice services. Billions of dollars have been generated. More importantly, consumers have changed how they work and live, businesses have increased their efficiency and effectiveness, and productivity gains have benefited national and local economies that have realized the commensurate benefits of economic growth and development.

Similarly, the deployment of broadband communications has had a revolutionary impact on the accelerating economic and social development. A recent OECD report states that,

> ***Broadband connectivity is a key component in ICT development, adoption and use. It is of strategic importance to all countries because of its ability to accelerate the contribution of ICTs to economic growth in all sectors, enhance social and cultural development, and facilitate innovation. Widespread and affordable access can contribute to productivity and growth through applications that promote efficiency, network effects and positive externalities,, with benefits for business, the public sector, and consumers. Broadband networks are an important platform for the development of knowledge-based global, national, regional, and local economies.***[1]

Wireless broadband access, the marriage of two simple but powerful concepts, has the same potential to revolutionize the way Singaporeans live and work, and can further enhance their productivity and growth of the national economy. Additionally, while broadband is recognized as a key enabling technology, wired broadband connectivity is not available to all citizens due to various technological limitations in wired broadband access systems. New wireless technologies can provide broadband access to otherwise un-served communities.

The deployment of wide-area broadband wireless technologies typically enables operators to offer a range of services that includes fixed broadband Internet access,

[1] Organization for Economic Co-operation and Development, Directorate for Science, Technology and Industry Committee for Information, Computer and Communications Policy, *Broadband Driving Growth: Policy Response.* DSTI/ICCP(2003)13/FINAL, October 9, 2003.

fully mobile broadband access, and value-added transport services in both of those access modes such as secure VPN access and voice over IP. Wireless technologies have the ability to take broadband access to customers who wired technologies may not be able to reach cost-effectively. The ITU's latest figure for broadband lines per 100 pops in Singapore (1.8) suggests the Singapore market has been significantly underserved by current broadband access modes relative to other developed economies, and that the facilitation of more rapid broadband wireless deployment through innovative spectrum policy will have a tremendous positive impact on the penetration and use of the broadband Internet in Singapore.

Beyond simply increasing the availability and adoption of basic broadband access for both businesses and consumers in Singapore, with all the attendant and well-understood benefits the broadband Internet brings, *mobile* broadband wireless appears very likely to have an additional unique and very positive impact on the modes in which people work and play in the country. With the adoption of cellular phones exceeding the use of landline telephony by a wide margin in Singapore (72 per 100 pops for cellular v. 45 per 100 pops for landlines, per the ITU's latest figures), there is no doubt that the populace already understands and values highly the ability to communicate where and when they choose. Analysis of occupational statistics for developed economies like Singapore's has shown that at least 30% if not 40% of the total workforce is engaged in activity that takes them out of their primary workplace regularly. Gartner's latest statistic for laptops' share of total PC sales in Singapore, which stands at about 40%, reflects this reality and suggests the workforce stands ready and able to tap the value of mobile broadband.

The feedback from trial users and now the commercial subscribers for the iBurst broadband wireless network that covers Sydney, Australia, indicates that for those many itinerant workers, ubiquitous, mobile broadband offers huge benefits in their ability to manage where and when they work. The increased flexibility of having true broadband speed available wherever they are, whenever they want it, enables a whole new degree of access to their company's information and applications or reference and transactional material on the worldwide web. Beyond the simple benefit of making their travel or between-meetings time much more productive, the considerable improvement in accessibility greatly enhances the value proposition of web-based applications in both intra- and extranet environments. Fundamental improvements in business model flexibility are already being seen. Within only a couple months' worth of commercial operation in Sydney, the iBurst network is already beginning to transform the accessibility of work and information -- disassociating location, activity, and data in new and flexible ways that have long been expected of the Internet, but are just now being realized through the unique operating modes that only broadband wireless can enable. These effects are being seen across a wide range of industry segments, from financial services to software to entertainment. Given the already intense mobile communication habits of the Singapore people, these positive and profound transformational benefits of mobile broadband data are likely to be realized quite quickly.

(b) Views and comments on the allocation of the 2.3 GHz and 2.5 GHz bands for wireless broadband technologies and the harmonization of spectrum at the border areas. What are the coexistence issues that need to be considered with regards to the deployment of systems (FDD & TDD) in the same geographical area in adjacent frequency blocs and the deployment of systems across geographic boundaries in the same frequency blocks? What are the technical assessment and methodology to be used for the deployment and coordination of systems, including separation distances, power spectral flux density limits, out-of-band-emission limits, frequency guard bands etc., to ensure coexistence of system operations? What are the mitigation techniques that could be employed in case of co-channel interference between systems operating in adjacent geographical areas?

Does the 5 MHz, 5.5 MHz or 6 MHz channeling plan for the 2.3 GHz band and the 2.5 GHz band meet industry requirements? What is the appropriate duplex separation (Transmit/Receive) for the FDD wireless broadband technologies in the 2.3 GHz and 2.3 GHz bands respectively? What is the minimum, as well as optimal amount of spectrum required by an operator for specific geographical deployment or nationwide deployment? Please provide supporting reasons for each comment and proposal made.

[ArrayComm Inc]

Many countries have allocated 2.5 GHz bands for MMDS services. However, the actual deployment of services in this band is limited, in some cases due to the adoption of technical rules that are ill suited for the deployment of a mobile broadband wireless access systems. The US is in the midst of an outstanding rulemaking that will revise its technical rules for the deployment of systems in this band in the US. The results of this rulemaking is likely to have a major impact on the type of systems that will be brought to market in the US and may influence allocations and service offerings in other markets, as well.

In the Republic of Korea, the world leader in broadband penetration has announced its intention to allocate the 2.3 GHz band for portable wireless (broadband) Internet access. It is anticipated, based on recent standards decisions in Korea, that the 2.3 GHz band will be allocated in unpaired blocks for TDD systems. TDD has several distinct advantages for broadband wireless access systems because of its improved facility in supporting data-centric services and ability to maximize the spectral efficiency of the radio resource using adaptive antenna technology and advanced spatial processing techniques.

Coexistence Issues

Even between similar systems, adjacent band TDD systems or adjacent band FDD systems, for example, co-existence issues arise. Their impact can be lessened by an appropriate regulatory regime. OOBE limits should be as stringent as is economically and practically feasible for the capabilities and deployment practices of today's equipment. This alone will significantly improve spectrum utilization and simplify the introduction of new, more efficient radio technologies.

We believe that allocation of either the 2.3 GHz or the 2.5 GHz band into unpaired blocks supporting TDD systems would provide the most spectrally efficient arrangement to enable deployment of a mobile broadband wireless access services.

However, we recognize that the Government of Singapore may wish to make some of this spectrum available for use by both TDD-based and FDD-based systems. If so, then all potential licenses would benefit from an allocation that eliminates, or at least minimizes, the possibility of coexistence problems between TDD and FDD systems operating in adjacent frequency bands in the same geographical areas or in the same frequency bands in adjacent geographical areas. Since the market would benefit from an allocation that is technologically neutral, any allocation of spectrum for both FDD and TDD systems should provide for flexibility and for efficient utilization, and requires significant creativity.

Technological neutrality must be balanced by business realities and engineering practicalities. Allocations that earmark specific portions of the band to one technology and designate other spectrum for another technology would be ideal from a co-existence perspective, but can misjudge the market. The result can be low utilization in one part of the spectrum and overcrowding in another. A regime that makes no attempt to foster co-existence between adjacent licensees' operations, however, may produce co-existence problems that cannot be practically solved, that significantly increase network deployment time and costs, or that necessitate large internal guardbands. Spectrum employed as guardbands is not used to provide services to end users, the public.

It is clear that interference is apt to be more frequent and more severe when dissimilar technologies (e.g. ,TDD and FDD) seek to co-exist in the same geographic area on adjacent or nearly adjacent channels. Technological "fixes" can be employed to minimize the interference, but always with attendant costs of capital and spectrum efficiency. The ITU has studied the problem of TDD/FDD coexistence and has developed two reports on the subject, the second of which details the mitigation techniques that can be used to address the problem scenarios identified in the first report.[2] [3] Analysis of the coexistence issues that may exist between adjacent TDD and FDD systems depends on specific knowledge of the technologies that would be operating in adjacent frequency bands or in adjacent geographic areas. These reports demonstrate that mitigating techniques exist that can improve coexistence situations. However, few are universally applicable and their use entail additional costs, tradeoffs and consideration of their drawbacks, versus the use of guardbands and /or increased geographic cell separation. We encourage the Government of Singapore, if it decides to allocate spectrum for both TDD and FDD systems, to minimize the number of situations in which these systems occupy adjacent bands and adjacent geographical areas.

All of the 3G technologies and almost all of the newer non-3G wireless broadband technology from various vendors work in multiples of 5 MHz spectrum. As a result, for the most efficient use of spectrum the channelization plan should be made in blocks of 5 MHz spectrum to not leave any 'orphan' bits of 0.5 or 1 MHz. We believe that TDD technologies are more suited for data applications. They can easily support asymmetric traffic, enjoy much better spectral efficiencies and economics than FDD systems due to powerful proven techniques like smart antenna technology and hence

---

[2] ITU-R Report M.2030, *"Coexistence between IMT-2000 TDD and FDD Radio Interface Technologies Operating in Adjacent Bands and in the Same Geographical Area."*

[3] ITU-R Draft New Report M.[COEXT], "*Mitigating Techniques to Address Coexistence between IMT-2000 TDD and FDD Radio Interface Technologies Operating in Adjacent Bands and in the Same Geographical Area,"* 8F/069Rev2, approved by WP8F on 24 February, 2004.

are more suited for a successful operating business for a wireless broadband rollout. However, we do understand IDA's stance for some FDD spectrum allocation but have no comments on the duplex separation for those technologies.

We believe that a minimum allocation for wireless broadband operator must be 5 MHz that would enable rollout and operation in the initial years. Further 5 MHz must be allotted for future expansion. Limiting the spectrum to this amount allows multiple operators to have access to it and provides competition in the market to benefit the end user. It also fosters use of 'spectrally efficient' wireless broadband technologies that make the most efficient use of the spectrum. Given that good usable spectrum for any wireless service is finite and that the new upcoming services are more spectrally demanding (and growing), it is imperative that IDA encourages technologies that use spectrum more efficiently rather than allot huge chunks of spectrum blocks to solve the capacity issues.

(Kyocera Corp)

Although diffusion of the disturbance wave by CDMA and communication on the multi-carrier by OFDN are the example, the adaptive array technology which iBurst uses is a very effective technology which minimizes disturbance between channels. In the iBurst system, 5MHz channeling is desirable. The optimal spectrum is 5MHz.

(c) Views and comments on the key features and service obligation to be applied for auctioning the spectrum for the deployment of wireless broadband technologies. If the key features are not appropriate, please provide supporting reasons why they

are not.

(ArrayAsia Pte Ltd)

We are aware of the Singapore 3G auctions, where the reserve price was reduced to $S 100m from $S150m for each operator, and the spectrum went at the reserve price.

There were no takers for the LMDS spectrum auction; which came at a time when the telecommunications market globally was in severe downturn. Thus even though the auction design may have been per the description in para 4.2, in fact it was never implemented. Similarly as there were only three contenders for the 3G spectrum (all existing 2G players); the spectrum was allocated at the reserve price.

Spectrum auctions can have the effect of requiring up front cash investment, not in the network or product & service development, but in fees which may be seen to be a tax on top of cost of doing business. Although the Singapore approach of not seeking to fill treasury coffers by having what was considered to be a reasonable reserve amount for the 3G spectrum was and is applauded, the world of telecommunications has changed further since the 3G spectrum allocations were done. In particular much of the world has experienced economic downturn and Singapore itself has not yet fully recovered. The recovered model will see a world of much greater cost pressure and thinner and thinner margins. We see greater commoditisation.

The experience of questionable business cases for 3G and the WiFi experience are telling as to the future of broadband wireless. Newer players in the game now may not have the backing of the larger established local or foreign firms, but these players may well be the one which have a better ability to be low cost and thus have good prospects of success.

We thus encourage the IDA to consider not using an auction approach, rather using a 'beauty contest' approach.

Specifically, the requirement to lodge a 'Banker's Guarantee' (in effect an unconditional undertaking, which would require the bidder to provide 100% cover – usually by way of a cash deposit) to cover the offers. If the reserve price is high or if new entrants find the guarantee quantity a barrier to entry, then the business case may be hard to justify.

On para 4.4, while the two year rollout obligation may seem reasonable, there may be some key dependencies which need to be accommodated. Further, for this kind of service, an island wide 100% coverage may not be warranted at least initially.

We also support the use by existing 3G operators of the spectrum which they have acquired already, for deployment of mobile wireless broadband services, like iBurst.

We do not believe however that an 'equivalence' approach should be taken to spectrum pricing – ie if 3G operators paid $S 100m each for the full 3G spectrum, aiming to ascribe a value to spectrum to be made available now by reference to the 3G allocation may not be a useful benchmark as:

- Times have changed
- The technology is different as is the business case.

We agree that keeping the allocation of an FBO licence separate is sound, where the licence fee for the FBO is nominal.

(d) Views and comments on whether spectrum should be auctioned in generic lots or in blocks with specified frequencies; the appropriateness of the lot sizes; and the maximum amount of spectrum to be set.

[ArrayComm Inc]

Please see our reply to question 9.1(c) regarding the desirability of allocating spectrum in 5 MHz blocks initially and allowing additional 5 MHz blocks to be obtained in the future to accommodate growth. We also believe that while either generic lots or specified frequency blocks would support the deployment of a broadband wireless access service, the industry would benefit from having the additional certainty that would result from allocating blocks with specified frequencies. By "generic lots" we are assuming that the operators would specify the endpoints of the licenses they are seeking. If this is a correct assumption, such a system could result in stranding slivers of spectrum between licensed blocks, leaving those slivers incapable of supporting any service.

(Kyocera Corp)

If IDA does not prepare a guard band between lots (i.e., if each operator has to have their own guard band), 5.5MHz or 6MHz is desirable. However, if a quota lot is arranged in consideration of the feature of a system or IDA prepares a guard band between lots, it will be better to allocate in a 5MHz block.

(e) Views and comments on the deployment of wireless broadband technologies in the 3G spectrum bands. Are there any technical considerations that IDA should consider? Please provide detailed supporting reasons for each comment and proposal made.

[ArrayComm Inc]

While the bands identified for 3G services are ideally suited for the provision of mobile services, the systems based on 3G standards have not delivered on the promise of mobile broadband wireless access. All of these systems, based on the evolving the radio and network technologies used for provision of second generation mobile voice services, are based on a circuit switched architecture that is ill suited for supporting IP-based data applications. Additionally, the economics of using 3G systems to provide mobile broadband wireless access limits their applicability to supporting only moderate data rate transmission from cell phones. 3G systems cannot be used economically to provide for truly broadband Internet access in a mobile environment to a large number of users simultaneously.

While 3G technologies have not fulfilled their promise, other new systems utilizing highly spectral efficient technologies have been developed and are commercially available to provide a fully mobile, fully broadband wireless Internet access capability. The iBurst system, mentioned earlier, is one such wide area broadband wireless system that is capable of providing continuously connected or "always-on" high speed data services, usually at speeds more than 50 times faster than dialup access rates which support standard applications such as email, web-surfing, remote access, banking and streaming video to customers located at home, in the office, in the park or on the move. As such, iBurst complements rather that competes with both 2.5 and 3G systems, as well as the wireless LAN systems that are part of the broadband wireless landscape. In Australia, the iBurst system operates in the 1905-1910 MHz band that is considered to be 3G spectrum. By providing regulatory flexibility and technology neutrality, the Government of Singapore can reap the same benefits for its citizens as are enjoyed by the citizens of Australia whose government allocated 3G spectrum without mandating the use of 3G technology. It should be noted that there are no other commercial deployments of mobile broadband wireless access service in the 1900-1920 MHz band using 3G-compliant systems anywhere in the world, including Australia.

(Kyocera Corp)

3G may not necessarily be the optimal technology as a WBB system. The view of IDA that a door is opened to the technology produced after ITU decides upon the standard of 3G is welcomed. However, when these 3G systems are employed in the same frequency band, interference with other systems should be considered . The regulation in the employment of Part 24 in FCC and employment by 1.9GHz in Australia gives a good solution.

Views and comments on the eligibility of existing 3G and broadband infrastructure providers for the 2.3 GHz and 2.5 GHz spectrum, and the limit on the spectrum amount for which they could bid.

(ArrayAsia Pte Ltd.)

Existing broadband providers could usefully deploy services in this spectrum. But they will need to have the technology to enable them to do it. ArrayAsia does not see spectrum as the only limitation, but supports the idea of a cap on the amount of spectrum an existing broadband provider or 3G operator can have, in order to foster development of the market.

(f) Views and comments on whether there are issues that may pose problems to achieving transparent and seamless interconnection and open access. IDA further seeks comments on the type and level of QoS standard that will be appropriate and whether the existing set of QoS standards for broadband service providers are applicable for service delivery using wireless broadband networks. Please provide supporting reasons for each comment and proposal made.

[ArrayComm Inc]

We believe that the wireless broadband technology deployed in Singapore should have the flexibility and the interface to seamlessly interconnect with the content/service providers that are there serving the wireline broadband market. We believe this enables economies of scale on the service provider side and allows them a new 'wireless' access mechanism to new class of subscribers.

It should be recognized that wireless service is inherently different from wireline service in several aspects. While they enjoy the benefits of faster rollouts, mobility, cost effectiveness, the wireless coverage can be limited in buildings and coverage holes may exist in parts of the network. Hence service guarantees in ALL parts of the network is difficult and expensive to maintain. As a result, we believe that it is not possible to impose the existing set of wireline broadband QoS standards over the wireless broadband services. IDA should let the services provider define these criteria as a part of their service offerings to the consumer.

(Kyocera Corp)

Although it may not be directly related to QoS, it is desirable to also take into account the most efficient use of the available frequency into consideration for development of the future of a WBB service which uses limited frequency.

(ArrayAsia Pte Ltd)

We see an evolution in broadband wireless technologies.

The IEEE roadmap [refer to chart from IEEE website which shows the 'any to any' platform model] has as a longer term goal, the ability to use these technologies for data and voice and will eventually treat data and voice as just applications on top of an IP based network.

Devices for broadband wireless evolve from a PC card (in iBurst's case the Kyocera PCMCIA card for example), to embedded chip (eg Centrino or Airport) to a card plugged into or embedded in a PDA, to a handphone.

Not all applications (eg. Voice) will be supported on day 1.

There is no common standard yet for most wireless broadband technologies. While WiFi operates on 802.11 with a very common standard for 802.11(b), even today for the 802.11 (g) standard, it is commonly accepted that some devices (PC cards and Access Point stations) are not fully compatible.

The difference is currently even greater as regards the space for technologies which are comparable to 802.16 and 802.20. ArrayAsia believes strongly in widespread use of the technology; the business models for example support multi-provider (eg. In Australia, PBA is a wholesaler).

Interconnect can be achieved in a way through the world wide web; thus data is not such an issue.

Use of the technology for voice, MMS etc will require some compatibility. ArrayAsia believes that a roadmap of interoperability is useful and relevant, but notes the cautions above about the assumptions.

QoS standards. We consider the standards in Annex 1 to be reasonable but caution that the service activation time of 5 working days or fewer should only apply to retail (not wholesale) and should not be confused with the question of coverage.

(g) Views and comments on the Market Trial Licence framework and the specific features set out in Annex 2. Is the market trial licence framework conducive in helping market participants test the commercial viability of innovative service? Are there additional reasons for each comment and proposal made.

(ArrayAsia Pte Ltd)

ArrayAsia generally supports IDA proposals in this area. Re Annex 2 – on the operating conditions, the idea of leaving interconnection to commercial negotiations is sound in principle. We note that one player in particular has resisted this in the past and some assistance from IDA may well be needed in order to support market development

9.2 Respondents are also invited to comment on any other issues not covered in this consultation document but which are considered to be relevant in the deployment of wireless broadband technologies.

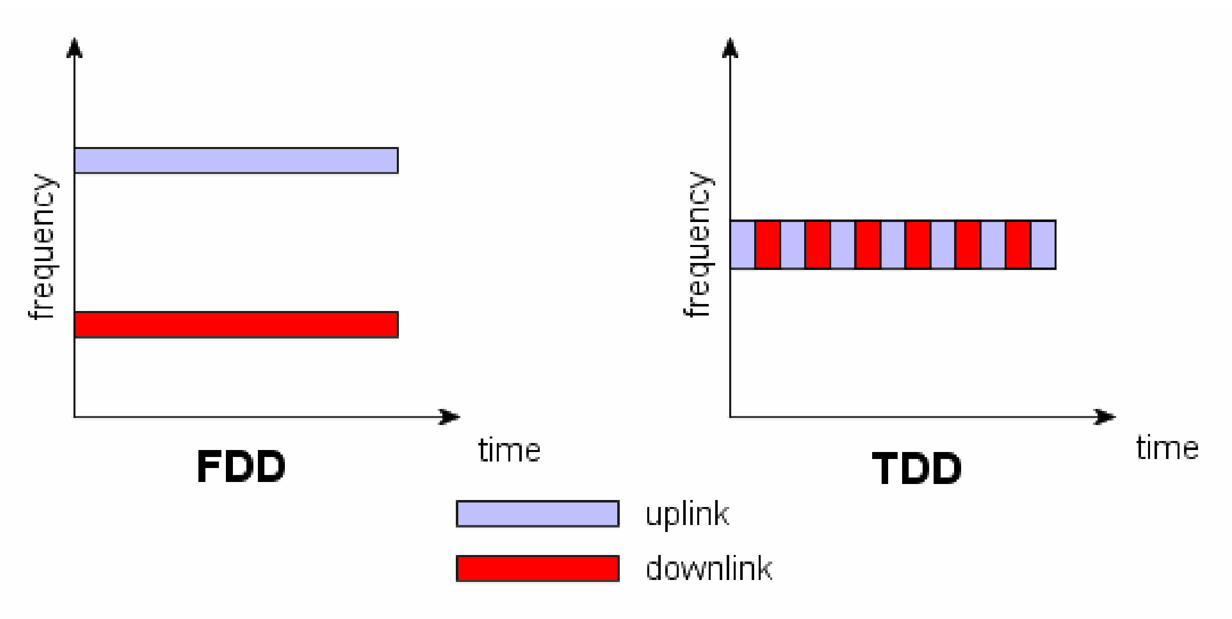
[ArrayComm Inc]

As stated earlier, TDD technology is uniquely well suited for the deployment of mobile or portable broadband wireless access systems. We would like to take this opportunity to further expand on the technological advantages of TDD systems and further encourage the Government of Singapore to allocate unpaired spectrum blocks that can be used by TDD systems.

The TDD advantage

All two-way communications systems require separate channels to convey information in each direction: *i.e.,* from the network to the end user and from the end user to the network. Creating bi-directional channels in this fashion is called "duplexing." Wireless duplexing schemes generally can be divided into two classes:

Time Division Duplexing (TDD), in which the directional channels are separated in time, and Frequency Division Duplexing (FDD), in which the directional channels are separated in frequency.



Most commercial voice systems use the Frequency Division Duplex approach (*e.g.,* all of the major cellular communications standards across the world are based on FDD). This technique is well established for voice networks and is well suited to the symmetrical nature of two-way voice communications.

Time Division Duplex systems fundamentally can improve the spectral efficiency of spectrum use and also are best suited to "packetized" traffic for wireless Internet applications.

Allocation of Underutilized Spectrum:

Conventional FDD cellular systems require slices of spectrum to be paired, which complicates the already burdensome regulatory challenge of identifying suitable spectrum for a given service. This is exacerbated by extensive demand for spectrum from both commercial and government entities. Conversely, TDD allows the use of unpaired frequency bands that stand alone, allowing regulatory bodies the freedom to release spectrum that would otherwise lie fallow.

Data Capacity and Efficiency:

TDD derives maximum benefit from innovative technologies such as adaptive antenna array systems (a technology in which ArrayComm, Inc., is both a pioneer and world leader). The combination of TDD and adaptive antennas creates spectral efficiencies that are more than 10 times greater than those of conventional FDD systems. TDD naturally supports the inherent asymmetrical nature of packet data traffic, and therefore is a better platform than FDD for Internet and multimedia services.

The Application of TDD in Wired Networks:

Ethernet is a familiar example of a TDD system. In concept, Ethernet stations share a single cable in a random-access fashion. When any station wishes to transmit, it checks to see if the cable is available – *i.e.,* that no other station is transmitting at that moment – and transmits its message if the cable is clear. Thousands to millions of messages can be transmitted each second over this single shared bi-directional resource.

TDD in Wireless Networks:

TDD systems are deployed globally, providing a wide range of services. An example is the Personal Handyphone System (PHS), a wide-area TDD cellular system providing voice and 128 kbps data services for millions of subscribers throughout Asia. The European DECT standard and Wireless LANs are also TDD systems. Wireless LANs in particular are TDD and inherently designed to support efficient transport of packet data.

Wireless Technology and Spectral Efficiency in TDD and FDD systems:

The throughput that a wireless system achieves over its spectral resources is described as its "spectral efficiency" – measured in bits/second/Hertz/cell. Spectral efficiency provides a quantitative way of comparing the performance of wireless systems. The higher a system's spectral efficiency, the more users it can support, and the higher the bandwidth per user. This translates directly to the cost of delivering information – and thus, on companies' ability to derive revenue from each unit of radio spectrum.

TDD has a fundamental benefit over FDD in that advanced interference mitigation technologies such as adaptive (so-called "smart") antenna arrays generally provide greater benefits with TDD technology than with FDD technology. The main limiting factor in the spectral efficiency of cellular systems is self-interference. The effect of many users attempting to use the same block of spectrum in a given geographic region is that they create radio interference for one another, eventually reducing each other's grade of service below an acceptable level.

Technologies that mitigate interference increase the number of users that can share radio resources. The greatest gains here are realized from adaptive antenna array systems that selectively distribute and collect energy from within the cell. Although adaptive antennas provide benefits to both TDD and FDD systems, the improvements in spectral efficiency are a factor of 10 higher for TDD systems[i].

TDD Systems and Packet Data Traffic:

TDD is also particularly advantageous for packet 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. Furthermore, the degree and direction of asymmetry can vary over time. For example, a residential consumer surfing the Web could be generating 20 times as much downlink data as uplink data; a single mouse click could easily result in many large image files being transferred to her machine. When uploading files or images to his Web site, that same consumer could reverse the asymmetry of his data, to be 20 times greater on the uplink.

Achieving the same level of efficiency in FDD systems, where the relative fractions of uplink and downlink resources are predetermined by spectrum allocations, is more challenging. In a situation where the majority of the traffic is downlink traffic, for example, the bulk of the FDD system's uplink resources lay fallow.

Despite these differences, it would be inappropriate to characterize the emerging wireless landscape as a battlefield for TDD and FDD wireless systems. In fact, ***both*** will play a significant role in delivering tomorrow's wireless services, each according to the strengths of its transmission model. FDD delivers most cellular voice communications today, and 3G networks are expected to continue this legacy. Paired frequency bands are well-suited to voice communications, which require symmetrical bandwidth allocations for transmission and reception.

But for data performance, TDD is unmatched. Its use of unpaired frequencies maximizes available bandwidth for transmission and reception, and its asymmetrical bandwidth allocations optimize data delivery as needed. Likewise, TDD's superior integration with smart antenna technologies results in substantial improvements to network capacity.

TDD for Wireless Internet Systems:

Beyond its technical benefits, TDD's use of unpaired frequencies simplifies network deployment by facilitating spectrum allocations and maximizing the value of previously underutilized wireless frequencies. TDD systems are poised to play a significant role in tomorrow's wireless marketplace, optimizing the use of precious spectrum resources as it delivers superior performance for broadband packet data services to the consumer.

[i] The transmit and receive frequency in a TDD system is identical, whereas the frequencies for transmit and receive for an FDD system are different. In TDD systems, therefore, there is an inherent reciprocity of the propagation in each direction. There is a reduced correlation between the uplink and downlink radio channels in FDD systems as compared to TDD systems, since the transmit and receive frequencies are different. Adaptive antennas, when implemented at the base station, rely to a large extent on uplink measurements to formulate a strategy for downlink processing. To the extent that the uplink and downlink radio channels differ, *e.g.,* due to operation at different frequencies, the performance of the downlink processing is degraded. Therefore, the fidelity of the adaptive antenna array processing and the resulting gains in spectral efficiency are significantly better in TDD than in FDD systems.