Gigabyte Performance in a Mobile Broadband Network

Voice and Data Services over a Converged IP Network

Whitepaper

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Flarion Technologies, Inc.

Bedminster One

135 Route 202/206 South

Bedminster, NJ 07921

Tel: +1 908-947-7000

Executive Summary

As the industry moves towards Mobile Broadband networks that go beyond current 3G capabilities, the attention of mobile operators has been to consider and evaluate the deployment of technologies based on OFDM (Orthogonal Frequency Division Multiplexing). In particular, there is a high probability that mobile subscriber data utilization requirements will actually outstrip the capabilities of current and evolved network technologies. Mobile networks in the very near future will have to be capable of supporting thousands of customers consuming Gigabytes of data per month.

This raises the question of network capacity, in particular with regard to IP data traffic and the complexities of managing IP packets across a true end-to-end All IP link. This is highly relevant to "Triple Play", the convergence of voice, data and broadcast service delivery that will be built around IP. For Triple Play to be viable for operators, especially in a mobile context, high capacity and a superior level of user experience must be a given.

An evolved circuit switched mobile technology with a layered packet data capability will struggle to scale economically to deliver the kind of capacity performance mobile operators will demand. Since spectrum is a limited and often costly resource, technologies must address capacity and scalability, as well as cost of delivery, in order to guarantee the performance needed for operators to address new market opportunities. In addition, the cost of delivering Gigabyte performance must be at a low enough level to ensure rapid market adoption.

This reality is now available with FLASH-OFDM® and Flexband™, a breakthrough in the delivery of cost effective network capacity. Operators world-wide can now start to seriously address new markets and service delivery opportunities.

FLASH-OFDM and Flexband can and do deliver market leading capacity, supporting thousands of users per sector consuming Gigabytes of data per month. A myriad of services become possible -- from IP voice to VPN access, from music to games, video to broadcast IP TV, plus much more. With delivery costs as low at $10 per subscriber per Gigabyte of data per month, operators have for the first time the real potential to advance their business and rapidly address new revenue generating IP data delivery opportunities.

1. The Move to OFDM-Based Networks

After over 20 years of successful growth using circuit switched technologies, the mobile telecommunications world is moving to OFDM based networks. OFDM is now recognized by a growing number of companies and organizations as the future for high capacity wireless and mobile data networks due to the technology's unique interference limiting advantages.

OFDM is the technology earmarked for "beyond 3G" networks and is currently used in various audio and video broadcast standards, as well as in WiFi and fixed wireless access technologies like WiMAX. 3GPP is currently reviewing submissions to use OFDM as a future enhancement to 3G, and the CDMA group has announced its future move towards OFDM-based air-link solutions. Global operators such as NTT DoCoMo, Vodafone, T-Mobile, and Telstra have publicly announced OFDM based network trials. Vendors such as Siemens, Nortel, and Motorola have all demonstrated high-speed data solutions using OFDM. While most of these Megabit per second demonstrations are lab based, using up to 100MHz of bandwidth, Flarion is delivering a commercial grade Mobile Broadband solution today for 1.25MHz and 5MHz network deployments.

The growth in mobile communications is currently focused in two distinct areas; Mobile Telephony and Mobile Broadband Data. Operators are pushing mobile telephony growth toward the 2 billion-user target, much of which will come from developing countries. While Mobile Telephony is a mature technology serving a mature market, Mobile Broadband Data is a nascent technology for a new market to address last-mile, mobile and converged broadband services over packet-switched networks. Mobile operators, cable operators and service providers are competing for business and consumer Triple Play services (on-demand video, voice and broadband data). To compete, Triple Play communication providers need capacity, scalability and a low-cost network capable of supporting Gigabyte consumption of data, per subscriber, per month, at a reasonable network cost.

2. The Fundamentals of FLASH-OFDM

Flarion's FLASH-OFDM air interface is designed to transparently and economically support all existing IP-based applications in a mobile, wide-area network deployment. The technology is designed for use in licensed, bandwidth-constrained spectrum operating in a frequency division duplex (FDD) mode. FLASH-OFDM technology possesses the necessary attributes for mobile deployment, including power and spectrum-efficient operation with support for full mobility and quality of service, while providing broadband data speeds with only a single antenna at the wireless terminal. It has been designed from the outset to integrate into an IP-based network in a *seamless* fashion, as it was recognized early on that IP technology provides the most cost effective path to providing converged voice and data services.

The performance of FLASH-OFDM is well verified and accepted by the industry, in particular, downlink peak sector data rates of 3.2Mbps, sustainable sector data rates of 1.25Mbps, uplink peak sector data rates of 900kbps, and 500kbps sustainable uplink sector data rates. While peak data rates and bits/Hz/second are relevant, it is the ability to deliver a highly sustainable sector data capacity to thousands of users that marks the next phase of Mobile Broadband Data development.

3. The Fundamentals of Managing IP Broadband Data

The Mobile Broadband community appears to be focused on peak data rates and bits/Hz/second. Bragging rights center around which technology can deliver the highest peak data rates, claims that are often unrealistic in real world network deployments. Unlike peak rates, the sustainable sector throughput is highly relevant as a direct indication as to how many users can be served by a given technology; but even the sustainable sector throughput is only one part of a highly complex story. The ability to efficiently manage individual data packets from thousands of fixed and mobile users with a limited amount of spectrum is what separates FLASH-OFDM from other technologies.

Any technology's ability to effectively utilize bandwidth and serve a large number of active users requires high performance in a number of critical areas:

Packet Management:

- The ability to manage and interrogate individual packets at the IP layer. This ensures maximum control of data and enables operators to manage QoS.
- Fast ARQ, to ensure that lost or corrupted data is retransmitted instantaneously. This ensures low latency and high performance in the air-link.
- Low latency is a vital parameter, since TCP/IP does not make a distinction between congestion and delay. High latency causes TCP/IP to reduce data rates and the size of the packet window, resulting in an inefficient air-link for IP data.
- Sustainable sector Downlink and Uplink data rates. Peak data rates are less relevant since it is the actual usable data rate that determines the efficiency of the air-link and the number of users that can be supported within a given bandwidth with a certain quality of service. The Uplink sustainable data rate is equally as important as the Downlink, since recent experience shows that Mobile Broadband Data use migrates to a more interactive 50-50 downlink-uplink traffic model, compared to the often quoted 70-30 downlink-uplink Web traffic model.
- Edge rates are also a key area of consideration. Data rates for all spread spectrum technologies are impacted by interference from adjacent cells, especially at the cell borders. Increasing cell edge data rates has been a key focus for Flarion and is the cornerstone of the innovative Flexband solution.

State Management:

Traditional wireless systems know two states: ON for sending and receiving traffic and SLEEP for power conservation. The dilemma with the old two state model is the fact that data is bursty, intermittent and highly random, making it difficult for two state systems to manage their users and resources effectively. Being ON is required for a responsive look and feel of the network but wastes terminal power and system resources that can't be made available to other users when the ON-user is not actually transmitting data. To resolve this problem, Flarion pioneered the HOLD state to facilitate fast transitions to and from the ON state. The benefits of this three state design are manifold:

- Dramatic reduction in terminal power for 'idle' users;
- Quadrupling of the active user pool for greater scheduling efficiency and resource utilization; and
- Super fast transition from HOLD to ON for high performance.

Service Management:

Mobile Broadband operators are looking for ways to provide differentiated services. This includes offering a variety of Mobile Broadband services ranging from Web browsing, email, instant messaging, file transfers, VPN, media streaming and voice. The experience from the fixed broadband world is that if the service is sold based on maximum peak data rates – 1Mbps, 512kbps, 384kbps, then the only differentiating factor is price. While this can drive customer growth, it does not provide a way to deliver differentiation and premium pricing.

With FLASH-OFDM technology, operators can deliver Mobile Broadband access for a flat fee and then layer additional access service fees on top. This enables Premium Access services; Platinum, Gold, Silver, etc., family packages for evening and weekend users, as well as innumerable other combinations.

4. FLASH-OFDM with Flexband

Flexband technology is a breakthrough in the delivery of high-capacity, high-performance on-demand video, voice and data services. Flexband greatly simplifies network design for 1.25MHz and 5MHz OFDM multi-carrier systems and delivers a true broadband user experience while cost-effectively scaling to support Gigabyte-consuming mobile broadband subscribers throughout the entire cell-coverage area, particularly at the cell edge.

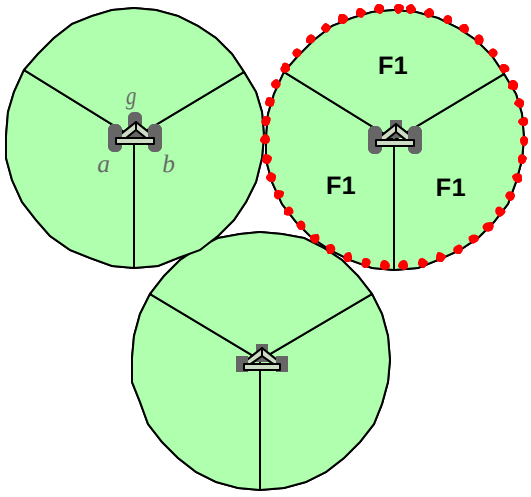
Flexband leverages Flarion's BeaconTone™ technology, which in a FLASH-OFDM system ensures a premium-operating environment for each individual subscriber, maximizing data capacity and throughput across the entire network. BeaconTone technology enables subscriber devices to continuously monitor in-band interference and instantaneously select the most optimal carrier to deliver maximum bandwidth and performance. The combination of Flexband and BeaconTone technologies improves the subscriber experience, network efficiency and operator capacity to deliver high-bandwidth services.

4.1. Flexband Configurations

Flexband 1x 1.25MHz Carriers: N=1

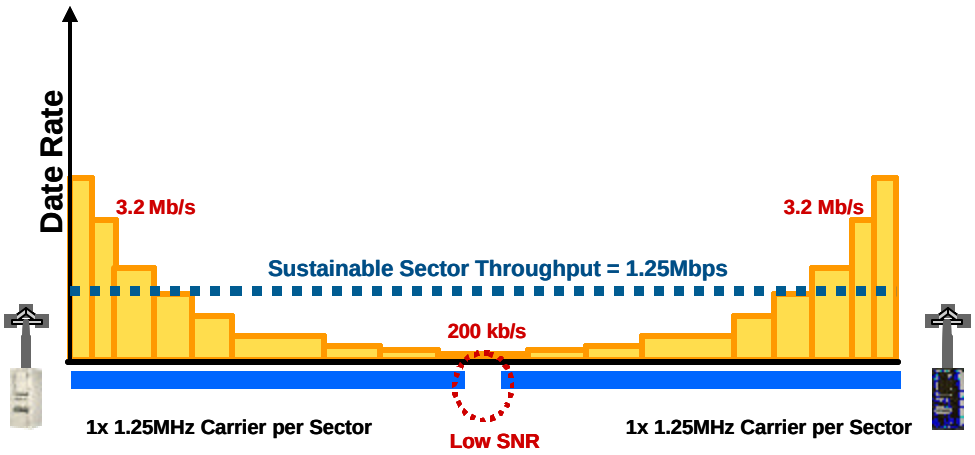
FLASH-OFDM operates with a single 1.25MHz carrier network, using the same frequency in each cell sector. Typically, a cell is populated as 3 sectors, in a 1+1+1 configuration. When the same frequencies are used in each sector, it is known as an N=1 system (the frequency is reused in every sector).

Flexband can be used with a single 1.25MHz carrier network (N=1) and will benefit from increased data rates and increased voice capacity. The limitation of any single 1.25MHz carrier system is a reduction in data rates at the cell edge due to the low Signal to Noise Ratio (SNR) in that portion of the coverage area.



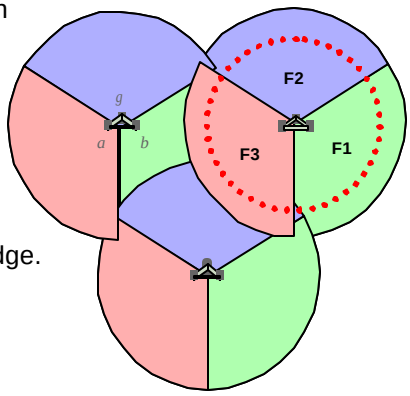
Performance can be viewed as though traveling down a highway. Close in to the center of the cell, the highway is smooth and traveling speed can be high. Further away from the cell center, the highway becomes uneven and speed is gradually reduced, while at the cell edge, the

highway is more rugged and speed slows further, until the smoother road is reached in the next sector. Flexband uses multi-carriers in either an N=3 or N=1 configuration to combat this situation and increase overall capacity.



Flexband 3x 1.25MHz Carriers: N=3

The Flexband 3x 1.25MHz (N=3) configuration requires three separate 1.25MHz carriers reused every 3 sectors. Each cell site uses 3 carriers, one in each sector, and this pattern is repeated in every cell site in the network. An operator therefore needs 3.75MHz of spectrum, plus guard band, so 5MHz in total. Adjacent cells are configured to ensure that the same frequencies are radiating in different directions so interference at the cell edges is minimized. This results in higher throughput across the whole cell area and a substantial increase in sustainable sector data rates, especially at the cell edge. While this Flexband configuration requires 5MHz of spectrum in total, each sector is only utilizing a single 1.25MHz carrier.



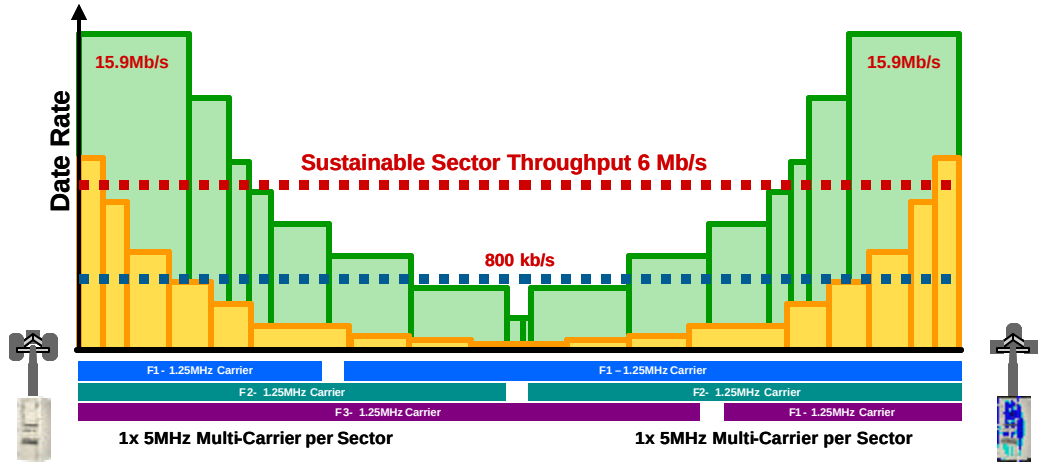
Flexband 1x 5MHz multi-carrier: N=1

With the fully equipped 5MHz multi-carrier configuration (N=1), 3x 1.25MHz carriers are used in each sector. This is repeated in every sector in the network (N=1). Each of the three carriers are power scaled to create inner, middle and outer coverage cells. Adjacent sectors are power scaled to fill in the coverage, in effect, overlapping into adjacent sectors as needed.

As can be seen from the diagram on the next page, each individual carrier pair has a low SNR in a different region of the cell area. This means that terminals will always have at least 1 or 2 adjacent carriers to hop onto that are not at a low SRN in that region of the cell.

BeaconTone technology ensures that the terminal is constantly updated on the level of SNR on all available carriers and enables the terminal to instantly initiate handover to the most optimal carrier at any time. The result is a substantial increase in edge data rates and a dramatic increase in sustainable sector throughput.

Using the previous highway analogy, as the road becomes uneven, the traveler, instead of slowing down, utilizes BeaconTone technology to evaluate if there are better adjacent lanes, and if so, moves to the smoothest road offering the fastest traveling speed. This constant evaluation process carried out by the terminal ensures that maximum speed is achieved at all times.



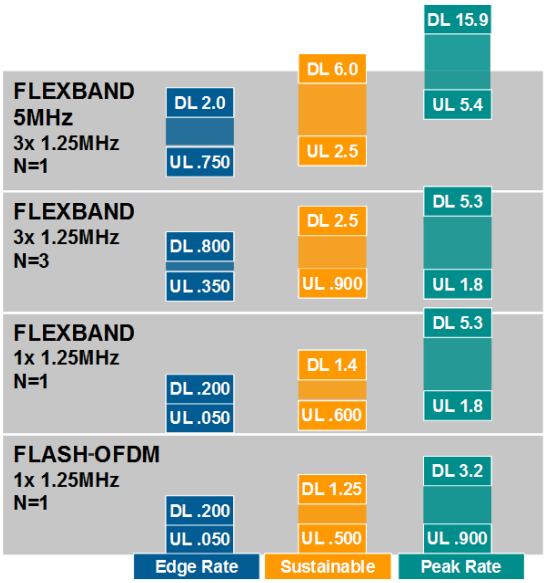
4.2. BeaconTone Technology

Every carrier in the FLASH-OFDM Flexband system transmits a beacon signal at full power. The terminal is constantly measuring all available beacon signals and evaluating which is the most optimal carrier in order to ensure the highest data throughput. Based on this beacon information, the terminal decides when it should hop onto another carrier, either in the same cell or in an adjacent cell. In this way, the terminal avoids areas of low SNR, which results in an increase of between 5-6dB in Signal to Noise Ratios at the cell edge. Due to the lower interference levels across the whole sector, it is possible to utilize higher levels of coding in more of the cell area, delivering substantially higher peak data rates and superior performance for sustainable data rates in both the Downlink and Uplink.

4.3. Flexband Sector Data Rates

With a fully equipped FLASH-OFDM Flexband 5MHz multi-carrier system, operators will be able to deliver an increased sector data rate of 15.9Mbps peak in the Downlink and 5.4Mbps peak in the Uplink. Sustainable sector data rates increase to 6Mbps in the Downlink and 2.5Mbps in the Uplink.

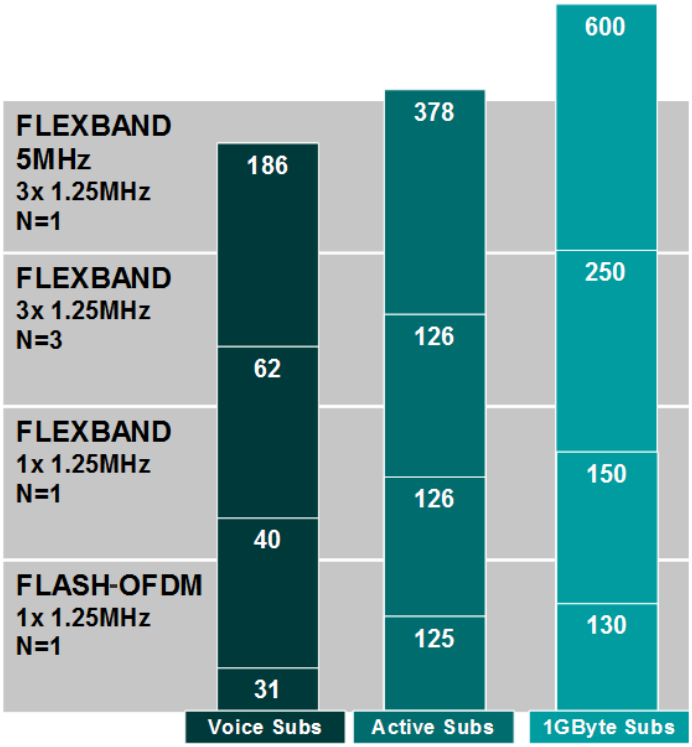
With the Flexband N=3 configuration, cell edge data rates increase from 200kbps to 800kbps sector peak, delivering a 4x performance advantage. The 5MHz multi-carrier solution delivers a peak sector edge Downlink data rate of around 2Mbps.



For Flexband to deliver peak performance, operators should ideally have a minimum of 5MHz of paired spectrum, however, operators with less than this will still be able to deploy Flexband. An operator with only a single 1.25MHz carrier will experience an increase in the Downlink peak sector data rate of 5.3Mbps and a sustainable sector data rate of 1.4Mbps.

4.4. Flexband Sector Capacity

The result of this increase in network performance is a corresponding increase in subscriber capacity. Early results of market trials suggest that when customers are provided with a Mobile Broadband connection, usage migrates to replicate fixed broadband usage. In other words, data usage per subscriber moves from downloading Megabytes of data per month to downloading Gigabytes of data per month.



Flexband enables an operator to efficiently scale its FLASH-OFDM network to meet these rapidly evolving customer requirements.

FLASH-OFDM supports up to 130 1Gigabyte consuming subscribers per sector. Flexband increases this to 600 1Gigabyte consuming subscribers per sector. This is the highest capacity of any Mobile Broadband technology using 5MHz of paired spectum.

Voice Capacity

Flexband also delivers an increase in voice capacity by increasing the number of simultaneous “ON” users from 31 to 93. This results in a doubling in the number of voice calls from 31 to 62 per sector. For those operators with only a single 1.25MHz carrier, there is an increase to 40 calls per sector due to the limited improvement in Uplink capacity.

With a fully equipped 5MHz multi-carrier system, there is an increase to a ground breaking 186 voice calls, ensuring that operators have enough capacity to target new market segments such as the fixed to mobile convergence (FMC) opportunity.

5. The Economics of Delivering 1GByte of Data for $10

The cost of delivering the high level of capacity needed for new markets is also critical, otherwise mobile operators would find it increasingly difficult to compete with fixed line incumbents who are also looking at Triple Play converged solutions. In addition, FMC is more than just making all voice mobile; it is also about making data and broadcast services mobile.

With FLASH-OFDM and Flexband, the cost for delivering 1GigaByte of data per customer per month is as low as $10. This figure has been validated with several operator business cases and is based on realistic and achievable criteria. In addition, a business case built around a national deployment in the 1.9GHz spectrum was created to further validate the capacity, scalability and costs of deployment for a FLASH-OFDM network with Flexband.

5.1. Business Case: Nationwide Network Overlay at 1.9GHz

The FLASH-OFDM business case considered an operator deploying a data overlay network in the US at 1.9GHz using 10MHz of spectrum. In the first 3 years, roll out is coverage driven, eventually covering 227 million POPs. Thereafter, the network becomes capacity driven as growth and usage increases. The operator's existing base stations are upgraded with a FLASH-OFDM blade, which is the most cost effective solution for rapid deployment. CapEx cost for the upgrade was less than $2 billion. Total network costs included CapEx, OpEx, depreciation and Sales, General Administration and Marketing Expenses. Revenue per subscriber (ARPU) started at $50 in year one, falling to $39 in year seven. Revenue was modeled based on a data only service assuming that voice revenue would come from the existing network. Revenue figures were based on the initial subscriber growth being driven by corporate users with the bias changing over the period of the model to consumers.

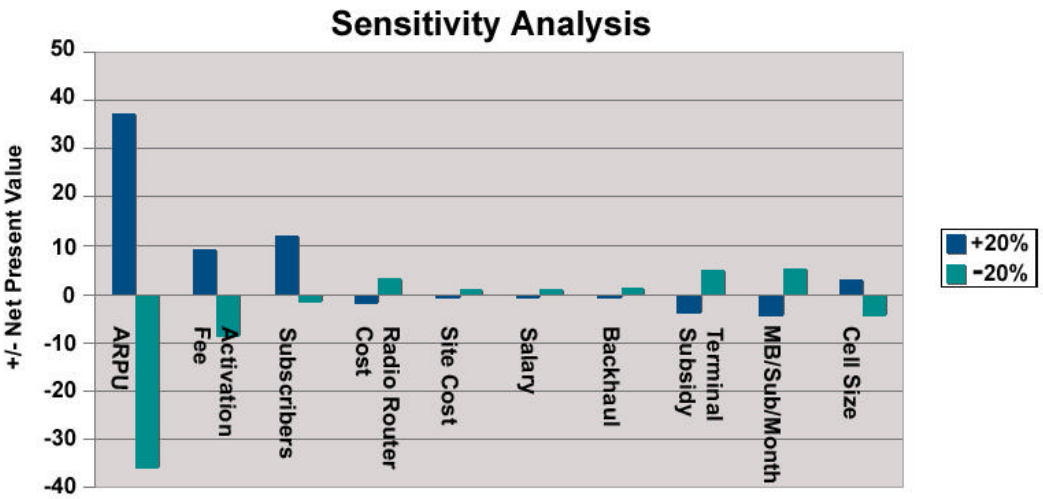
Subscriber growth scaled from 0.03% market penetration in year one to 6% penetration with an average subscriber base of 14.4 million customers in year seven. At 1.7% market penetration, the business case was cash-flow break-even with ARPU at $44.

Data usage was set at 1Gigabyte per user per month in year one rising to 2Gigabytes of data per user per month in year seven. The objective being, to evaluate the performance of a FLASH-OFDM network and test if it would scale cost effectively in a large Gigabyte/user/month delivery environment.

This resulted in delivery cost of 1Gigabyte of data consumed per user at $9.8 per month by year seven.

Sensitivity Analysis

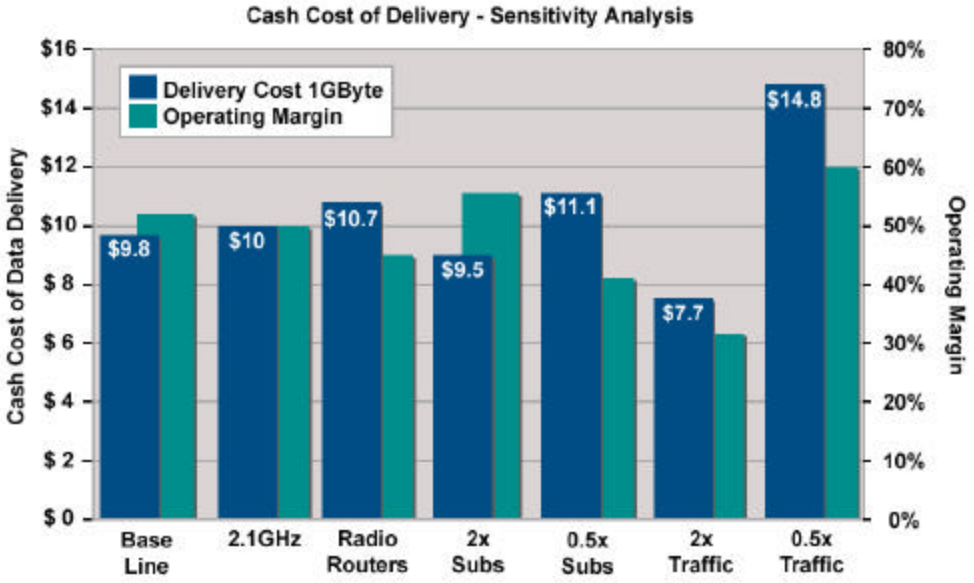
The impact on the business case of variations of +/-20% in costs and growth concluded that ARPU, the Number of subscribers and Activation Fees, had the biggest impact on the Net Present Value of the business case. The capital cost of the FLASH-OFDM RadioRouter® base station had a limited impact on the business case, as did most of the other sensitivities analyzed.



The changes in ARPU has the biggest impact on the business case, which to some degree is not surprising, while CapEx, especially the FLASH-OFDM network costs, had far less impact than may be expected.

Clearly the focus for operators is to build out a Mobile Broadband network that delivers a superior customer experience and creates the ability to increase ARPU across as wide a cross-section of the target audience as possible. Driving adoption and take-up then becomes the primary objective.

Secondary sensitivity analysis centered around changes in usage and can be seen in the graph below. Changes in data consumption resulted in the biggest impact to the business case especially the Cash Cost of Delivery for 1GigaByte of data and Operating Margin.



6. Delivering Gigabyte Capacity

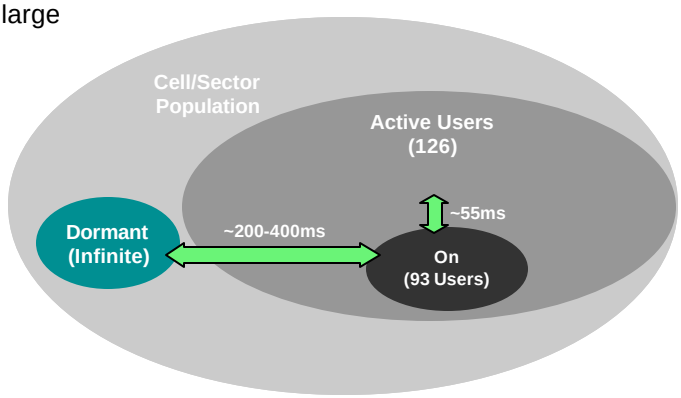
As previously identified, raw through-put is only one part in the complexity of delivering Gigabyte capacity in an All-IP Mobile Broadband network. One of the critical elements in delivering high sustainable data rates to customers is latency or Round Trip Time (RTT). RTT is the time taken for a packet of data to travel across the network and back again and is often referred to as network delay.

Research has shown that many applications fail to function effectively or even fail totally when latency levels exceed 100ms[1]. The desired objective then is to deliver low latency, even in a fully loaded network.

The way in which the radio interface schedules users in and out of service has one of the biggest impacts on latency. FLASH-OFDM network latency levels of less than 50ms continue to be validated in numerous operator networks. This is achieved in part due to the way the system schedules users in and out of the network.

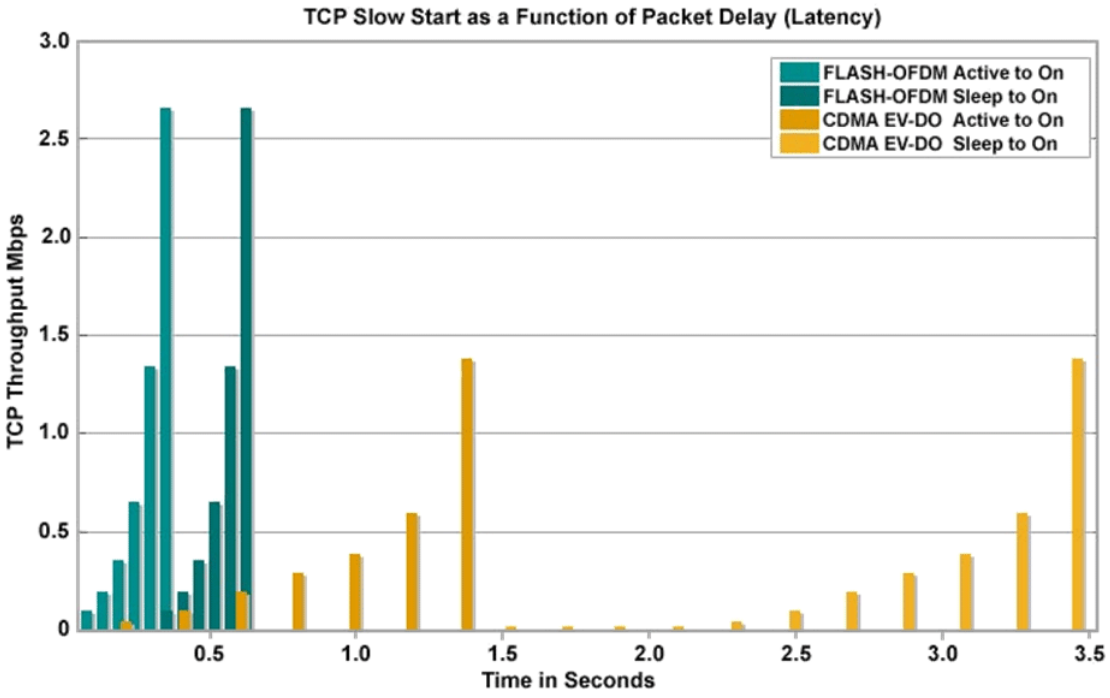
The FLASH-OFDM MAC (Median Access Control) layer allows wireless terminals to exist in one of a number of states: ON, Hold, Sleep, Hibernate or OFF. Each successive state between ON and OFF allows a greater degree of *power-save* operation, as power-efficient operation is always a key design criteria. A terminal is referred to as Active if in ON or Hold states, and Dormant if in Sleep or Hibernate states. It is the rapid transition from Hold to ON with very low levels of latency that enables FLASH-OFDM and Flexband to deliver Megabit/second sustainable sector data rates.

This is also one of the reasons that Flexband can support up to 600 1 Gigabyte consuming customers per 5MHz multi-carrier sector. Sector user capacity is mostly defined by two criteria: First, the level of both Downlink and Uplink ***Sustainable*** data rates (because 1Gigabyte users download and upload large amounts of data, peak rates do not guarantee a high level of usable data); and Second, the ***time it takes to transition*** users from Active (Hold) to ON and from Sleep to ON. Mobile technologies that have transition times measured in seconds and not milliseconds will be able to support far less subscribers, since during transition times the network resources are not available to other users.



Latency also impacts how rapidly TCP/IP ramps up and how quickly data is transferred across the air-link. TCP maintains a congestion window governing how many bytes of data a sender may send without acknowledgment from the receiver. When the sender infers network congestion - usually by failing to receive a timely acknowledgment of a group of bytes - the congestion window quickly closes to stanch the admission of any more data into the network; the congestion window slowly opens as congestion abates. The problem for mobile users stems from the fact that TCP does not recognize the difference between congestion and high air-link latency conditions. High latency mobile users will always be disadvantaged and throughput (data rates) will always be restricted.

[1] Metzler: 2004. "A LAN perspective on Wireless LAN requirements."



7. Conclusions

The industry is recognizing the validity of OFDM as the technology solution for high capacity IP based data networks. While many companies are now working in the area of OFDM and in particular in the area of mobility, Flarion Technologies is the only company that has focused exclusively in this area for the past 7 years. The result is FLASH-OFDM and Flexband – the most advanced mobile broadband access technology currently available.

Delivering a Triple Play solution requires a network that can be scaled to accommodate hundreds of user per cell, consuming Gigabytes of data per month at a cost at which operators can effectively compete and be profitable. Flexband is the first Mobile Broadband access solution that makes this possible.