

*Why ReFLEX has become the industry standard for wireless data delivery*

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## EXECUTIVE OVERVIEW

ReFLEX protocol based packet data networks are becoming the industry standard for wireless data applications because of their economic performance advantages and the fact the protocol is designed for long term migration to higher speeds and capacity as demand requires.

### Industry Standard Wireless Data Protocol

Industry analysts are projecting an explosive growth in wireless data users over the next few years driven primarily by consumers' needs for access to Internet based data (e-mail, instant messages and information on demand) and wireless e-commerce. ReFLEX networks are a preferred platform for these wireless data applications because, as described in this paper, they are engineered to deliver low cost, low bit error rate (BER) data over vast geographic footprints using small, inexpensive, always-on mobile devices that operate for weeks on a single AA battery.

In addition, ReFLEX networks are generally operated by companies focused on the single purpose of reliably developing, deploying and supporting wireless data applications. USA Mobility, MCI/SkyTel, PageNet, Arch Communications, USA Mobility, AirTouch and TSR Wireless all have investments based on the Motorola-developed ReFLEX protocol. These companies represent more than 30 million U.S.

subscribers – greater than 2/3 of the existing messaging industry subscriber base.

### Broadest Nationwide Network Coverage

Experience has shown that coverage is perhaps the most important requirement for broad-based deployment of wireless data applications to both businesses and consumers. Wireless service must cover users where they live, work, travel and vacation. ReFLEX networks already in use cover more square miles, including suburbs and recreation areas, than any other terrestrial wireless data network of any kind in the United States. ReFLEX coverage goes beyond major metropolitan areas and business centers to include hundreds of small cities and fast growing suburbs.

ReFLEX network coverage does not end at the U.S. borders. Canada and Mexico, the two most traveled countries by Americans, are also building out ReFLEX networks. Bell Mobility, a wholly owned subsidiary of Bell Canada, is building the Canadian ReFLEX wireless data coverage which will be commercially available before the end of the year. Telefonos de Mexico (Telmex), the largest telecommunications company in Mexico, is building in Mexico and is expected to have full coverage by mid 2001.

### Better Subscriber Equipment – Lower Cost and Broader Selection

ReFLEX protocol is optimized for high-speed wide area wireless data delivery using small, inexpensive, always-on, battery-powered subscriber units. Manufacturers are developing and shipping a greater variety of subscriber equipment for ReFLEX networks than for any other kind of wireless data network. There are multiple manufacturers of equipment for this market, and more are expected to enter the ReFLEX market soon. This diversity provides a greater range of existing messaging units from which customers can

choose and ensures access to subsequent generations of low-cost, consumer as well as business-oriented wireless data devices.

The newest device just coming to market is Motorola's Talkabout T900, expected to be broadly available in August of this year. The T900 is the smallest, lowest-cost and most consumer-friendly wireless e-mail and wireless instant messaging device on the market. The T900 will be a catalyst for consumer acceptance of "2-Way I-Messaging" services.

Glenayre provides two other subscriber device options. The Accesslink II is the lightest weight 2-way messaging device on the market. Messages are created on the easy to use virtual keyboard, allowing for one-handed operation and quick navigation through the device's intuitive folder-based user interface. The AccessLink II serves double duty as a wireless connection for PDAs via the infrared ports. The @ctiveLink is a 2-way wireless messaging plug-in module that enables the Handspring Visor to become a mobile Personal Information Management system.

No other wireless technology has comparable device performance and price points nor is expected to have in the foreseeable future. ReFLEX wireless data technology is also expected to become embedded by several manufacturers in personal digital assistants (PDAs) and in machine data modules for telemetry applications.

### ***Massive Retail Distribution to Consumers***

ReFLEX networks provide wireless data coverage to more retailers, than any other wireless data network in the U.S. For example, ReFLEX networks cover 90 percent of all RadioShack's 5,000 corporate-owned stores, creating an unparalleled retail environment capable of delivering the lowest-cost consumer device for wireless e-mail and wireless instant messaging. Comparatively, the Sprint PCS network, the largest single broadband footprint in the country, covers only 2/3 of these stores while the BellSouth Mobitex wireless data network covers even less. Coverage of a

major national retailer like Radio Shack is a good proxy for the ability of a wireless data network to be mass marketed to consumers nationally.

## **REFLEX NETWORK DESIGN**

### **ReFLEX Network Protocol**

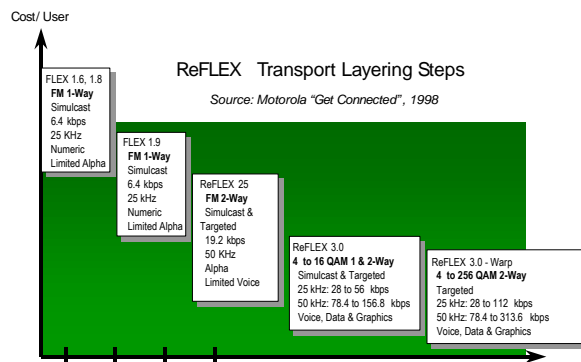
The ReFLEX protocol is uniquely engineered for reliable delivery of wireless packet data. ReFLEX has been selected by more carriers as the industry standard platform for light and medium wireless data load applications, such as e-mail, instant messaging, e-commerce, GPS locating, and Internet information on demand. Every commercially operating narrowband PCS licensee has committed to supporting the common version 2.7 standard ReFLEX wireless data protocol. In the authors' opinion, all will likely migrate to the new third generation (3G) ReFLEX as required over the next several years.

ReFLEX networks use state-of-the-art, software-configurable base stations that support multi-mode, multi-frequency communications. This allows carriers to migrate network assets, infrastructure and consumers to higher speeds and subsequent generations of ReFLEX as capacity needs and applications evolve. ReFLEX networks support data features such as token and broadcast messaging that hybrid voice and data networks will not or cannot implement in the foreseeable future.

One key benefit of ReFLEX network technology is its implementation of wireless "mesh networking" at the base station level that permits mobile devices to communicate bi-directionally with multiple base stations simultaneously. This delivers unprecedented always-connected service and coverage reliability for mobile devices compared to the single base station, single link implementation of all other packet data networks such as broadband PCS, Mobitex and RD-LAP networks.

The table below shows the plan for ReFLEX protocol migration subject to adjustment by the carriers, Motorola and Glenayre as required based on actual network loading and user requirements.

ReFLEX * Version	Mesh Simulcast	Channels/ 50Khz	Kbps/50k Hz
ReFLEX 2.0 4FSK	Yes	4	25.6
ReFLEX 3.0 4QAM	Yes	14	78.4
ReFLEX 3.0 16QAM	Yes	14	156.8
ReFLEX 3.0 256QAM	No	14	313.6



### The ReFLEX Protocol Design

Any modern communications network must be designed cognizant of the Internet and its protocols. This is certainly true of any wireless data network, since most of the "off-net" traffic will flow either from the Internet or from a private network using Internet protocols. The architects of wireless networks invariably are forced to come to grips with two aspects of the Internet Protocol (IP). First, its address plan is verbose and does not accommodate mobility. Second, its protocols are verbose and depend upon its address plan.

The designers of ReFLEX have adopted a far simpler address model, which does not embody any implicit or explicit notion of network or sub-network. This implies the complete ability of the mobile device to roam between serving areas of one or more service providers without modification to the mobile unit's address. That is, the ReFLEX address of a mobile unit is a global and intrinsic attribute, in contrast to the IP address of a networked host, which must be adapted to its current network location.

IP is a "balanced" peer-to-peer protocol. In contrast, ReFLEX supports an "unbalanced," host-to-terminal model. Said another way, ReFLEX devices do not have the inherent capacity to communicate with other peer units. Rather, they must always inter-work through the infrastructure of the messaging network, which provides store-and-forward message delivery functions that place a substantial onus on the sending host in a "balanced" protocol.

A very important mobile data requirement is that any battery-powered mobile unit must not unnecessarily bear the burden of message delivery, as it does under the Transport Control Protocol (TCP). In an IP network, using TCP as the method for assuring message delivery between two mobile units, intermediate routing systems provide no inherent store-and-forward functionality. If the sender is in good coverage and the receiver is in poor coverage, TCP would place the onus for retries on the sending mobile device. The common physical link and network layer protocols – Ethernet, IEEE 802, and IP – provide no mechanisms to compensate for the vagaries of UHF mobile radio interface.

The introduction of store-and-forward agents in the network creates a fundamental imbalance in the communication pathway between communicating end units. Almost everyone will be familiar with this effect in the context of simple mail transfer protocol (SMTP) and post office protocol (POP) servers. While it would be perfectly feasible for two Internet hosts to send messages directly using SMTP, this is almost never done. Instead, mail servers are established and the end hosts communicate with the mail servers using a POP.

This has the distinct advantage of allowing mail to be relayed through various post offices to the one closest to the end host without that final host even having to be active on the network. It has the disadvantage of increasing message latency by virtue of the delays through the relay network and in the need for the receiving host to poll its POP server.

In a low-latency mobile messaging network, in which communicating end units are in good coverage and active on the network, it would be undesirable to force mobile units to poll servers for messages. This implies a set of network functions that has little, if any, comparison in the Internet.

### ReFLEX and the Internet

It is absolutely necessary to inter-operate effectively with Internet protocols such as SMTP for email, http for web traffic, and so on. Again, the designers of ReFLEX have accounted for this requirement. ReFLEX supports a recursive stack model, which is in some respects even more sophisticated than the linear stack models of TCP/IP and ISO OSI. The protocols of the ReFLEX stack are collectively referred to as FLEXsuite. For most of the dominant Internet protocols, there exists at least one corresponding FLEXsuite protocol type<sup>1</sup>. FLEXsuite also supports the common set of MIME types as well as the wireless applications protocol (WAP) extensions.

All of this taken together implies a capability to transport arbitrary binary content from an Internet host to an arbitrary application running on a ReFLEX mobile device, and to have that application recognize how to process the data based upon content identifiers. This is the essence of the present success of the Internet—the ability for applications on one host to transport arbitrary content to applications on another host with absolute disregard for the intervening network elements.

<sup>1</sup> For SMTP e-mail, there are two: mailto and wireless e-mail (WEM). Mailto supports a simple interface. WEM supports full RFC822 headers and corresponding functionality.

Three broad models of interconnect to the Internet are available: a bearer service, a teleservice, and a teleservice supplementary. In the bearer service model, it is assumed that the Internet host has the capability to encode and decode FLEXsuite. In this case, pure binary content is provided to the ReFLEX network, which transports the content untouched to the mobile device<sup>2</sup>. In the teleservice case, an Internet protocol, say SMTP, is mapped onto a FLEXsuite protocol, for example the FLEXsuite protocol mailto. In the teleservice supplementary case, an Internet protocol, again say SMTP, is mapped onto a FLEXsuite protocol, for example WEM, and in addition, the ReFLEX network provides supplementary services such as mail-box filtering, store-and-forward guarantees, message compression, mail re-routing, and attachment stripping.

### ReFLEX Air Interface

At the air interface, ReFLEX supports guaranteed communications at the physical, link, and network layers. In terms of the data link layer, ReFLEX uses a pair of simple error detection and correction methods, far simpler<sup>3</sup> than those employed in cellular or wideband PCS protocols. In contrast to cellular air interfaces, ReFLEX employs a much more complex simulcast channel<sup>4</sup>, on the forward (network-to-mobile device) path, and an adaptive diversity channel on the reverse (mobile device-to-network) path. Likewise, the forward channel power levels used in ReFLEX are typically an order of magnitude stronger than in cellular systems. The conclusion is that ReFLEX radio links usually operate at a lower raw BER than cellular links in the same location. Also ReFLEX forward channels will

<sup>2</sup> Currently, the ReFLEX industry is moving to adopt common protocol – wireless communications transfer protocol (WCTP) – for the delivery of binary content.

<sup>3</sup> The forward link protects user data with a (21,32) BCH code. The reverse link protects data with Reed Solomon code (31,23). Cellular systems typically use layered error protection codes with a rate 1:2 or rate 1:4 convolutional code, at a minimum, on top of some further cyclic or block code for error detection.

<sup>4</sup> A typical ReFLEX air interface involves dozens of transmitters, timed by GPS, and optimized with offsets obtained by simulated annealing.

show less correlated bit error patterns than cellular in similar locations.

So the usual cellular system operates on a Rayleigh BER curve versus carrier to interference. And it is in the interest of cellular service providers to maximize their network capacity by operating their voice services as close as possible to the poorest raw BER that they can afford. This maximizes the frequency re-use in their cellular plan. It also implies a poor starting point for a high-grade data service. In order to compensate for this, it is conventional to add high levels of error protection.

In fact, such extreme levels of error protection are necessary under the most marginal of link conditions that there is almost no user bandwidth left. Therefore, these networks are usually made adaptive in the sense that the link quality is monitored and the channel coding is altered on the fly to maximize user data throughput. Unfortunately, this optimization is difficult for short data bursts. It works best for a continuous data stream, so that the adaptation logic has something to work with. This makes any interpretation of average or worst-case user data throughput characteristics challenging at best.

This trade-off of user bandwidth for coding protection in cellular systems is interesting in contrast to the design philosophy of ReFLEX. Since ReFLEX does not start with a connection-oriented voice component, it could be designed for high performance, bursty, short data messaging from the start. The contrasting assumption in ReFLEX is that the mobile device is either available to the system, or not. If not, as proven by the failure to deliver a message, then the system begins to search for the device. Full details of the search process are beyond the scope of this paper, but suffice it to say that the mobile device is either recovered by the network or it autonomously registers again. In either case, any pending messages are subsequently delivered at full speed.

It bears mentioning that in ReFLEX there is only a loose relationship between the base sites that are responsible for the delivery of forward channel

messages to the mobile and those that are responsible for receiving reverse channel traffic from it. As an extension, there is no necessary relationship between receiver site locations, antenna patterns, antenna heights, and so on, and those same attributes of transmitter sites<sup>5</sup>. In fact, it is generally desirable to offer a somewhat larger coverage footprint on the reverse channel than on the forward channel, to guarantee the mobile unit's ability to contact the system whenever it sees forward channel coverage.

In short, the RF design of the forward channel and reverse channel can be quite distinct in ReFLEX. Based upon design choices made by early implementers of the protocol, there has come to be an erroneous view that ReFLEX networks must have a much higher density of receive sites than transmit sites on the ground. This is not true, and recent implementations have been constructed with receive to transmit sites at a 1:1 ratio.

### ReFLEX Network Capacity Design

ReFLEX networks are capable of supporting increased offered load using an approach similar to cell splitting in cellular systems. This involves dividing a region that would otherwise be a simulcast zone in a traditional messaging network into distinct sub-zones, each with its own forward and reverse channel frequency assignments. This allows a ReFLEX network to have capacity growth in both directions similar to a cellular system, by reducing the effective area of coverage of a serving region. In cellular, this is a cell. In ReFLEX, this is a sub-zone<sup>6</sup>. Likewise, ReFLEX sub-zones do not all have to have the same capacity for load handling. One may have only a single forward and reverse channel, while a neighboring sub-zone may have several. And variations of the ReFLEX protocol supported in sub-zones do not all have to be alike. Therefore, dense regions of offered load can be served with high-density, high-capacity implementations of the

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<sup>5</sup> This allows ReFLEX zones to be configured as “two-way”, “partial coverage” or “one-way”; a feature that we’ll discuss later in this document.

<sup>6</sup> The number of sites in a sub-zone is highly flexible. It might include all sites in the parent zone or consist of only one site.

protocol, while outlying regions of a major metropolitan area can be served with a capacity commensurate with the offered load.

Returning to the trade-off of user bandwidth for error protection in cellular systems, we can tie error protection in ReFLEX to a similar trade-off; namely, the number of diversity channels in a sub-zone. The philosophy in ReFLEX is to use diversity instead of the complex error coding typical of cellular. Since there is no capacity driver in ReFLEX so strongly associated with frequency re-use, there is also no need to choose an operating point for the network with the absolute maximum of survivable raw BER as in cellular. This implies that cellular networks must claw their way back to an acceptable user BER with coding, sacrificing user data rate in the process. ReFLEX networks are meant to begin at an acceptable error rate at all points within the serving area.

Another aspect of the ReFLEX architecture is that the aggregate signaling rates on the forward and reverse channels are highly de-coupled. ReFLEX allows forward channel signaling rates of 1,600, 3,200, and 6,400 bits per second. Binary frequency shift keying (FSK) is used for 1,600 bps and can be used for 3,200 bps. Four-level FSK is used for 6,400 bps and can be used for 3,200 bps as well. On the reverse channel, ReFLEX allows rates of 800, 1,600, 6,400 and 9,600 bps. Four-level FSK is used for all reverse channel transmissions.

This doesn't completely describe the aggregate signaling rate in a market, however. In the forward direction, a number of transmitter sites will be synchronized for simulcast operation within a sub-zone. So all these transmitters are occupied with the same forward channel information stream, perhaps at 6,400 bps. Any given user might receive only part of that stream, but all devices would monitor the same shared information resource(s)<sup>7</sup>. On the reverse channel, mobile units that need to access the network

compete with one another on a part of the available bandwidth dedicated for this purpose. Since the transmit range of a mobile unit may be limited to only a few fixed sites within a zone, the aggregate raw information rate for all sites in the market will be the sum of activity at all of them. The aggregate non-redundant information rate will be less than this because of duplication in information received at multiple sites and representing the same mobile unit's transmissions.

Once a mobile station has succeeded in contacting the network on the contention part of the reverse channel, it may, for example, register with the network, or request specific information services, or request bandwidth for a long inbound message. If we follow the last case through, the network will validate the subscriber account, at the corresponding MS-H, and then send a forward channel command to the mobile unit that tells when to transmit the message. This allocation will be made in a part of the reverse channel that is reserved for such scheduled activity, in contrast to the contention access part. This raises several possible scenarios for the allocation of this scheduled bandwidth within a zone or sub-zone. In general, allocations within a sub-zone will potentially be "blocking." That is, if two mobiles were scheduled at the same time, their messages could interfere with one another destructively at one or more receiving sites.

The network may "overbook" the scheduled reverse channel resource when it determines that two subscriber units will not interfere with each other. An alternative capacity enhancing approach is to reduce the number of sites in a sub-zone to the point where overbooking would add little benefit. Part of the flexibility of ReFLEX is that it allows either, or neither, approach.

All of the above-mentioned capacity increasing solutions for both the forward and reverse channels need to be carefully orchestrated by the ReFLEX infrastructure equipment. Seamless sub-zoning and overbooking algorithms are collectively known as "software-based" capacity increasing solutions. Until the next generation protocol is commercialised,

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<sup>7</sup> A ReFLEX sub-zone can support several outbound channels. However, once a device is "camped" on a channel, it remains there until some event occurs that would cause it to drop off the air interface or chose a better channel.

software-based capacity increasing solutions represent the most cost-effective method of increasing the carriers' return on the investment on their frequency spectrum and network equipment. It is estimated that, when all of the ReFLEX 2.7-based software capacity enhancement is implemented, a nation-wide ReFLEX carrier will have the option of increasing the network capacity by at least 10 times over the ReFLEX networks currently deployed.

### ReFLEX Store and Forward Latency

A comparison and contrast of messaging latency in ReFLEX™ and cellular networks is a daunting task. Both types of wireless network face similar issues in inter-operation with the dominant Internet messaging protocol, SMTP. The most significant issue here with regard to latency is the aggregate of delays through the various forwarding agents and firewalls that are involved in Internet e-mail. The response of the ReFLEX industry to this issue has been the development of WCTP, a session-oriented protocol for messaging that employs an XML-tag protocol over http-push. Most Internet-sourced messages with mobile devices as destinations will likely employ SMTP up to a gateway maintained by the wireless service provider. Once traffic is received by the service provider's network, the inherent latency to forward the message to the appropriate radio link location will undoubtedly be slight in any well-maintained network<sup>8</sup>.

A more interesting question is how will the network decide what the most appropriate location will be? With what accuracy? And with what handling in the event of a delivery failure? None of these issues are resolvable in the air interface protocol itself. Rather, they must be addressed in the design of network elements, and in the protocols for their inter-operation. Although somewhat obvious, a message cannot be delivered to a mobile device that is off or out of the serving area or incapable of successful radio communication with the network for any other reason.

<sup>8</sup> Although it bears mentioning that the "control collapse" of the ReFLEX network will also have a bearing on the message latency both inbound and outbound.

In fact, the most extreme source of message delay is likely to be due to the link recovery processes in the event of a device being unavailable for communication. In current ReFLEX networks, these recovery processes are managed by network elements in the Wireless Message Transport Protocol (WMtp™) reference model, developed by Glenayre. The two most important of these are the Output Messaging Switch (MS-O) and the Home Messaging Switch (MS-H). It is the role of the MS-O to manage the mobility of a device within the scope of a serving market, often called a zone. It is the role of the MS-H to manage the mobility of a device across all of the zones of a service provider, including roaming onto the zones of another service provider. This MS-H management role includes both the grant and denial, for any reason, of service rights to a mobile device attempting to operate within an MS-O.

To those familiar with cellular networking, the role of the MS-H is closest to the combination of the Mobile Switching Center (MSC) and its associated Home Location Register (HLR). Likewise, the MS-O is functionally closest to the Visitor Location Register (VLR) of cellular networks. One notable exception is that in the WMtp reference model, all mobile devices are visitors in every possible MS-O. In fact, roaming in a WMtp-based ReFLEX network has little, if anything, to do with location. Rather, it has to do with the matching of service provider identifiers stored in the mobile unit, broadcast on the air interface, and advertised by WMtp elements.

A subscriber device is associated with only one MS-H, which is the anchor point for all forward and reverse channel messaging to it and from it. The MS-O acts as intermediary agent between the MS-H and the mobile unit. In the event of a communications failure at the level of an MS-O, the MS-H is informed of the failure. The original MS-O, and perhaps others, begins a search for the device. Recovery of the device by the original MS-O or by another one is signaled to the MS-H, and message delivery recommences. MS-O search procedures are adaptive<sup>9</sup>, and work with a variety of air

<sup>9</sup> An MS-O can be one of three classes: two-way, partial-coverage, or one-way. In a two-way zone, forward and reverse coverage is

interface parameters that are designed to ensure continuous and robust link availability.

Cellular and wideband PCS networks do not support much in the way of search. Rather, the onus is placed upon the mobile device to monitor and update its location relative to the fixed network. This is accomplished through a variety of time-based or location-based registration procedures. A specific example may be instructive. Consider a mobile device that happens to be momentarily out of coverage because, say, the user is in the sixth sub-floor of an underground parking garage. At this point, the network forwards a message, and in spite of any re-tries, it receives no acknowledgement from the mobile. In a voice-based cellular network, this would represent a missed call; and that call attempt is lost. Any search for the mobile is pointless. From the point of view of the cellular mobile, it may have lost contact with the network for a period, but it has no recognition of any failed message event. It is within the same serving region when it regains contact as it was when it lost contact. It will not register with the network on that count. The clock will tick inside the mobile until its registration timer elapses, and then it will register again. At this point, any pending traffic will be forwarded to it. Since the registration timers impact the behavior of all mobiles within the network, a reduction in the time to deliver any pending traffic to the mobile can only be achieved at the cost of increasing the polling rate of time-based registrations from all mobiles.

In contrast, in a ReFLEX network, there is a system parameter called the “incommunicado delay time.” If a mobile unit loses contact with the network for longer than this time, it is forced to register. In the messaging scenario just described, the mobile is either out of contact for a period less than or greater than the incommunicado delay. If it is less than this time, the system begins the search process, recovers the device when it is back in coverage; and the pending message is

immediately sent. If the loss of contact is greater than the incommunicado delay, then the mobile is forced to register, contact is established; and again, the pending message is immediately sent. Only devices that have been proven to be unavailable to the network by virtue of a failed messaging event or that have detected lost contact are subject to this search and registration process<sup>10</sup>. In summary, ReFLEX makes the process of short message delivery event-driven instead of polled.

These observations are also true of many packet data networks. Examples include those based on the Mobitex model. Mobitex supports message oriented applications using a “connectionless” packet model. In such a scheme, completely consistent with an adherence to the OSI protocol stack, any transport layer protocols that might provide functions to compensate for radio coverage issues are the responsibility of the communicating hosts. The layer 2 and 3 protocols at the Mobitex radio interface will provide four retries for any layer 3 protocol data unit. After this number of retries, failure of the layer 3 protocol data unit (often called a “packet” or “datagram”) is reported.

In a sense, this forces responsibility for mobility management upon the sending host. Since the sending host has no access whatsoever to information concerning the radio link to the receiving mobile device, its only mechanism is to re-send the data. Users of such networks may enjoy very low latency messaging *when* the destination mobile unit is in good coverage. On the other hand, designers of fixed-host to mobile applications may learn more than they ever wanted or needed to know about mobility management. Finally, mobile-to-mobile communications places an untoward requirement for communications management on the sending mobile.

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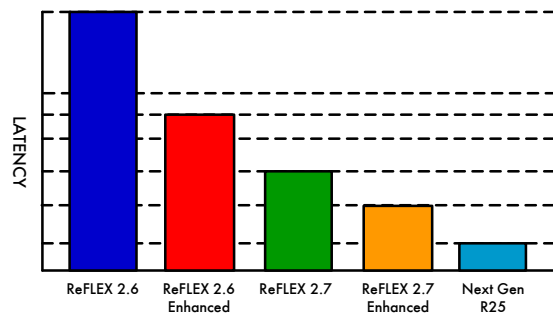
guaranteed to be equal. In a partial coverage zone, forward coverage may exceed reverse coverage. A one-way zone requires no reverse channel at all. Initial message delivery, any subsequent message re-try, and device search methods are all highly dependent upon this aspect of MS-O configuration.

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<sup>10</sup> There is a well-defined hysteresis mechanism built in.



For those application developers who do have the desire and expertise to achieve the lowest possible latency, it is important to present a view of the planned enhancements in the area of peer-to-peer messaging latency. With these enhancements implemented, a ReFLEX 2.7 subscriber device operating in “chat mode” will be able to achieve device-to-Internet latency of less than 10 seconds. Even further reductions will be possible with the implementation of the next generation protocol.



### ReFLEX Battery Consumption

In spite of the complexity of ReFLEX networks associated with store-and-forward and search functions, it is typical for ReFLEX devices to operate in coverage with normal use continuously for several weeks on a single AA battery. In some ways, they are truly always on.<sup>11</sup> In part, this is due to the efficiency of the ReFLEX air interface and its low consumption of energy per bit to signal the network. It is also due to the inherent capabilities for battery conservation and sleep cycles embedded in ReFLEX.

The ReFLEX air interface is synchronous, and it supports framed forward and reverse channels. Frames are of a variety of types: control, system configuration information (SCI), information services (IS), and targeted. Mobile units will have at least one unique personal address (for targeted messages). They may

<sup>11</sup> Later, as we discuss the notion of “collapse”, we’ll see how any “always on” device can “steal sleep” as a means of conserving energy.

also have one or more common information service addresses. Mobile devices must receive each of the first three types from time to time in order to remain in contact. Mobile devices with information service addresses must also wake up to receive IS frames from time to time. ReFLEX supports a model in which the control, SCI, and IS frames that are necessary for particular devices can be transmitted on a cyclic schedule. For example, considering device address modulo 8 may identify 8 groups of device. Then all members of each device group wake up in sequence to receive control, SCI, or IS frames pertinent to it. Thus, each device needs to attend to the air interface, in this case, only 1/8 of the time.

This concept is called “collapse” in ReFLEX. The collapse of a frame sequence is a small number that is interpreted as a power of 2 to result in the number of distinct device families attending to a set of frames. For example, a collapse of 3 corresponds to the previous 1 in 8 case. Control, SCI, and IS frames can all have different collapse values. Control frames include a variety of commands to specific devices. These all begin with the unique ReFLEX address of the device. Hence, it is possible for devices to awake on their control collapse schedule, test for the presence of their address, and not finding it, shut down their receivers.

If the device does sense its address, then it is further directed to the location of the information in the command being transmitted to it. One kind of command, or vector, is a further direction to the content of a message within a targeted frame. By increasing the control collapse, it is possible to decrease the amount of time that any device is active on the air interface. This trades battery life for latency. A ReFLEX frame is 1.875 seconds in duration, so 8 frames take 15 seconds. A collapse of 3 represents a significant benefit to the customer in terms of battery life, and yet a modest increase in message latency. Further increases in collapse can yield corresponding improvements in battery conservation.

It is worth noting that latency on the order of fractions of a second at the air interface demands constant electrical activity in the mobile unit. The design of

ReFLEX allows the operator of a network to provide improvements in battery conservation to subscribers while trading that gain for only modest increases in message delivery time.

### ReFLEX and SMS

It should be pointed out that there is one simple and obvious issue in contrast with SMS in cellular networks: IS-136 and IS-95 SMS protocols used by cellular only support forward SMS transport. So it is not immediately obvious as to how to get short alphanumeric messages into a switch on such a network. GSM-based services have an end-to-end SMS protocol as part of the ISDN, ITU-T Rec. Q.931 and SS7 call model and protocol base. The ISDN has a capability to transport a short package of alphanumeric information from one terminal to another as part of the control message normally sent to set up a phone call. In this special case, the message is moved from end-to-end through the SS7 network and intervening ISDN (Q.931) switches with a flag set that indicates *not* to establish a call. Since the GSM began with Q.931 and some extensions to SS7 as its base, GSM based wireless networks have an SMS mechanism to both send and receive short messages at the mobiles.

On the other hand, the North American cellular system protocols (EIA/TIA 553, IS-136, and IS-95) do not use Q.931 in the switches, nor does the North American PSTN generally use the same extensions to SS7 as are commonly available in Europe for the GSM. SMS functions have been added to allow outbound message transport in these protocols, but inbound messaging is an issue.

Even in the GSM, there are limitations to the SMS protocol's capabilities. Since the intended destinations are at phone numbers, Internet destinations are not naturally subsumed. Also, typical e-mail header functions are not supported, such as destination lists, reply-to fields, attachments, message threads, subject lines, and so on. Users who are familiar with Internet e-mail will find significant functional limitations here.

Some North American service providers have tried to augment the functional capabilities of their phones by adding multiple protocols into the units for data, including CDPD. The good news about CDPD is that it does support an IP-stack. The bad news is that it suffers similar issues with message transport as discussed above for Mobitex. Another limitation is that none of these hybrid systems are universally supported throughout North America. There are also rather odd "you can't get there from here" effects. Think of the CDPD function within a mobile trying to send an SMS message to itself. Does this traffic have to leave the service provider's own CDPD network in order to be reflected back into the addressing domain for SMS? The answer is probably yes, and with a corresponding increase in latency.

### ReFLEX and WAP

WAP has been presented as a cure-all for many of these problems. Interestingly enough, WAP was originally seen as a means to enable web browsing in mobile phones. In this scenario, a web browser in the mobile unit accesses web servers on the Internet. One of two cases arises: either the Internet web server is WAP-aware or it is not. If it is WAP-aware, then it sends its content using a special mark-up language<sup>12</sup> that is optimized for transmission over the limited bandwidth supported by cellular systems. If it is not WAP-aware, then its content is intercepted by the wireless service provider, and mapped onto the wireless mark-up language. As such, the WAP supported the transmission of signals representing web browser events from the mobile to the wireline web server; but it never contemplated bi-directional, peer-to-peer messaging between mobiles. Support for peer-to-peer messaging is only now beginning to be discussed in the WAP Forum, and largely in the context of interfaces to instant messaging (IM) networks, such as AOL's.

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<sup>12</sup> Wireless Markup Language (WML) instead of the Hyper Text Markup Language (HTML) or Extensible Markup Language (XML) that are usually transported by the Hyper Text Transfer Protocol (http).

Putting this in context, since the Europeans have an end-to-end SMS function in their GSM phones, they did not see a crying need to add it into WAP. But since the GSM SMS mechanism is ISDN-centric, it does not easily inter-operate with Internet-centric messaging models such as SMTP or IM. Internet-based e-mail by itself was not a big draw to European standards bodies, but IM is. However, do not expect the IM standards to be resolved anytime soon by a European standards body.

In the near term, the patch-work quilt of North American cellular and wideband PCS service providers are compromised by their lack of a common air interface protocol that will seamlessly support the basic function of receiving a data message from an application on one mobile unit and delivering it intact to another. Instead, what one sees is a set of isolated wireless domains with incompatible protocols that can only reach one another through Internet SMTP e-mail as a backbone.

The North American cellular service providers pay lip service to messaging services. Meanwhile, the industry press continues to forecast the impending doom to the wireless messaging sector – because of the wonderful data services to be supplied by cellular. Yet, the simple fact of the matter is that – outside of ReFLEX/WMtp narrowband PCS – there is no other network model that supports low-latency, high-coverage, wireless, Internet-enabled, peer-to-peer messaging. None.

## Messaging Security

Another factor of interest to wireless data users is the security of the service. Security pertains to a variety of service functions, including: customer data acquired during sales and activation procedures, location monitoring of their mobile device, privacy of their message content, malicious or fraudulent use of their accounts, denial of service attacks that reduce the utility of their service, and avoidance of viruses. A full discussion of security is beyond the scale of this brief review, but some comments on the privacy of message content over-the-air interface may be in order.

Privacy of messages is not an inherent property of the ReFLEX protocol, rather, it is supported within FLEXsuite. FLEXsuite supports the use of RC4 encryption using symmetric keys, meaning key pairs must be stored in both the mobile device and in some network-based encryption processor. There are three locations that make sense for the network-based encryption processor: within the messaging service provider's network, within a corporate network as an adjunct to the corporate e-mail backbone, or within an individual user's personal computer.

For low-latency peer-to-peer messaging, it is natural to place the key server/encoder within the service provider's network. In this way, the mobile sending the message uses its own key to cover its transmission in the reverse link, which is received and transferred to the key server/encoder within the network. At this location, the traffic is decrypted using a copy of the sender's key, and then encrypted with a copy of the destination's key. The encrypted traffic is then forwarded to the destination in the normal way. At the destination, the encryption protocol is detected and the incoming traffic is decrypted. The content is revealed and transferred to the appropriate destination within the receiving mobile.

The other two configurations are similar to the model just outlined, except the key server/encoder will be located at a corporate or personal location. Note that FLEXsuite currently does not support either of the two commonly available end-to-end privacy mechanisms used on the Internet – PGP or certificates<sup>13</sup>. Both of these privacy models use public key cryptography. Broadly speaking, public key methods differ from classical, symmetric key methods by breaking each user's key into two parts, one which may be revealed openly (the public key) and another which remains known only to its owner (the private key).

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<sup>13</sup> Pretty Good Privacy (PGP) is currently offered by Network Associates for a variety of computing platforms. It can be used with almost any e-mailer. It supports a "web of trust" model. Certificates and certificate authorities are supported by the e-mailers associated with Netscape's and Microsoft's web browsers. The associated key distribution protocols assume a centralized certificate authority that signs or authorizes user certificates/keys.

The use of public key cryptography has been proposed for the next version of FLEXsuite. In such a model, there would be no need for the decryption and encryption steps at any network location. Rather, the sending mobile would obtain the destination's public key, either by requesting it from the destination user or from some third party, which could include a public key database or certificate server. The sending mobile would then create a strong session key and encrypt it using the destination's public key. This session key would be used to encrypt the traffic for the destination with an efficient symmetric key algorithm<sup>14</sup>. A structured message would then be transmitted to the destination that would include the destination's address, an indicator of the encryption means used, the encrypted session key, and the encrypted message. This structured message would be passed as a binary message to the destination, which could be another mobile, an Internet e-mail user, or virtually any compatible application on any host computer on the Internet. At the destination, the session key is decoded using the destination's private key, and then the session key is used to decrypt the message contents.

The great advantage of this somewhat exotic process is that encryption and decryption is done only at the sending and receiving destinations, without a need for a significant number of keys to be stored at either end.

Consider for a moment why symmetric key cryptography rapidly becomes infeasible for this. Suppose that  $M$  senders of messages want to communicate securely with  $N$  destinations. With symmetric key methods, each of the  $M$  senders needs to have  $N$  different keys, one each for each destination. So, there are  $M \times N$  keys altogether. If the senders and receivers are in the same set, there are  $N^2$  keys in all. These keys must be kept secret, and shared only between the pairs of users that want to communicate between themselves. This makes support for even slightly more complex communication problems, like sending the same message to two or more destinations, increasingly difficult. In this case, the message must be encoded for each distinct destination, and the message

transmission repeated for each distinct encoded message. In a wireless mobile application, this rapidly becomes inefficient. As a result, the architecture described for ReFLEX is a highly common one, where all encrypted traffic passes through some shared network-based server. In this way, the  $M \times N$  key problem is reduced to an  $M$  key problem.<sup>15</sup>

With public key cryptography, to manage the same problem, there are only the  $N$  public keys of the recipients. These  $N$  public keys may be openly circulated. Taking the case of a single message to multiple destinations, the same session key may be encoded for each of the destinations using each destination's public key. A single message structure may be transmitted which includes the common encrypted message to all destinations together with the list of encrypted session keys, one per recipient.

These issues are shared by many modern wireless communication systems. For example, the GSM, North American IS-136 TDMA digital cellular and PCS, and IS-95 CDMA digital cellular and PCS, all use similar symmetric key mechanisms for privacy over the air interface. In these cases, the key servers can only be supported in the first, service-provider-located model<sup>16</sup>. ReFLEX/FLEXsuite narrowband PCS is unique in the sense that it can also support location of the key server/encoder outside of the service provider's network.

It is interesting to explore some of the results that occur from the support of the relocation of the FLEXsuite encoding point, or Internet proxy, from the

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<sup>15</sup> To allow multiple privacy encoding destinations to exist, FLEXsuite employs a distinction between master keys and session keys. A primary master key, called the A-key, is shared between the service provider and the mobile device. Any number of other privacy encoding points can use secondary master keys, called B-keys. None of these master keys are actually used for over the air message privacy. Rather, a new key, called an E-key, is generated from the appropriate master key and other shared data for each message. Each end in the communication process knows how to generate the correct E-key for message decoding. The privacy encoding points each have to store the master keys for each of the mobile units associated with them. Mobile units have to store distinct master keys (an A-key and some number of B-keys) for each point that can communicate privately with them.

<sup>16</sup> In other words, there are no E-keys.

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<sup>14</sup> Candidates would include DES, Triple DES, IDEA (used in PGP), and RC4.

service provider's network into a corporate or private environment. First, the Internet identity of the mobile unit is associated with the presence of the corporate or private network, and this remains "fixed" in a way that is transparent to the mobility of the user, without having to deploy Mobile IP. Hence, Internet protocol proxies for e-mail, web browsing, and the like, will operate as if the mobile were an integral part of the private domain, with whatever access to private network resources would be present to any fixed host within the private network. With FLEXsuite's capability to define arbitrary new protocol identifiers in a manner similar to the use of sockets on IP, this allows for an equally rich environment for the development of special-purpose mobile applications. Having spoken in favor of public key cryptography here, it should be recognized that a "full up" implementation is a daunting task. The primary driver for this implementation will be user demand. Nonetheless, there are no impediments in ReFLEX or FLEXsuite to an implementation of end-to-end public key; and in fact, it could already be supported for device configuration involving ReFLEX mobile units interfaced to PDAs.

Examples abound. Mobile sales staff may want to inspect an inventory database before placing orders. Mobile technical staff may want to check a trouble-ticket database to prioritize contacts on their daily routes. Mobile professionals may want to re-synchronize their personal calendars with a corporate or home office calendar application. If the corporation wanted to, it could provide whatever higher levels of authentication and privacy that it wished in order to support applications such as these.

### ReFLEX Network Model

A WMTp/ReFLEX network is best described in the context of a reference model. This model may not capture all of the possible detail, but represents a high level view from which some general observations can be made. Our reference model includes:

- a mobile device
- the ReFLEX air interface
- fixed sites
- a fixed site ReFLEX transmitter
- a fixed site ReFLEX receiver
- a fixed site GPS system
- a sub-zone
- a zone
- a communication back-bone between sites and the MS-O
- an MS-O (output messaging switch)
- an MS-H (home messaging switch)
- a communication backbone between MS-O and MS-H
- an MS-I (input messaging switch)
- a communication backbone between MS-H and MS-I
- the PSTN
- the ISDN
- the Internet
- a PSTN terminal
- an ISDN terminal
- a host on the Internet
- communication pathways between PSTN, ISDN, and Internet, and an MS-I

In the real world, these elements can be replicated any reasonable number of times. So, one or more mobile devices communicate with fixed site transmitters and receivers via the ReFLEX protocol at the air interface. All site equipment is synchronized to GPS time. The ReFLEX protocol specifies GPS synchronization. Fixed site transmitters and receivers are grouped into clusters called sub-zones. One or more sub-zones are grouped into a zone.

A zone, which includes all of the activity of fixed and mobile equipment within it, is managed by an output messaging switch. There exists some communication backbone between all of the fixed sites and the MS-O that manages them. This could be a number of options, including satellite-based using very small aperture terminals (VSATs), frame relay, fiber, ATM, LAN, WAN, Internet or other means.

There will be one or more MS-H. There will be a communication backbone between the MS-H and MS-O. Again, any number of means would suffice.

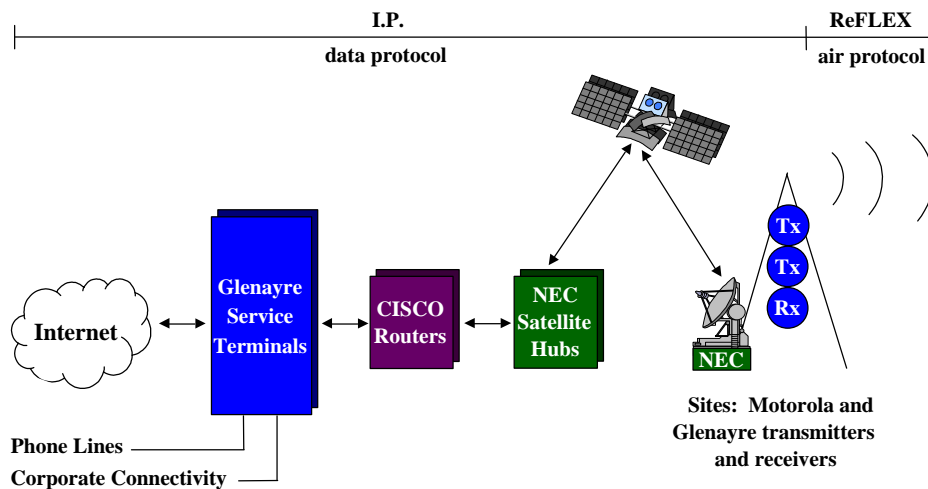
There will be an input messaging switch (MS-I) that manages traffic into and out of the MS-H. The Ms-I will be inter-connected with the MS-H by some means. Also, the MS-I will inter-operate with one or more public or private networks, such as the PSTN, ISDN, and Internet. Various terminals or hosts using one or more protocols on these external networks will transport messages intended for ReFLEX mobile devices towards the MS-I as a proxy for, or gateway to, the intended mobile device<sup>17</sup>.

**ReFLEX Network Operator Models**

Depending upon the design intent of any specific service provider, these network elements may be organized in a variety of ways. For example, one may

co-locate all of the MS-Is, MS-Hs, and MS-Os in a nationwide service offering in one common location. In that case, there is a requirement for back-haul of any telecommunications from all remote markets and the re-distribution of ReFLEX traffic to sites from the central location. To this provider, it is likely that the network out to sites – the MS-Is, MS-Hs and MS-Os and their LAN – and the gateways to the MS-Is represent distinct aspects to the network, each with its own operational concerns.

Another service provider may choose to place the MS-I, MS-H and MS-O for each market in that location. To support roaming within such a network, the provider will need an inter-connection mechanism among all market elements, perhaps a mesh of frame relay or ATM, or a fiber ring. In any case, to this provider, the natural elements are likely to be the set of MS-Is, MS-Hs , MS-Os and sites in each market; the network that inter-connects the market elements



**ReFLEX Network Design**

<sup>17</sup> The addressing model for the mobile unit must be compatible with the addressing plan of the source network.

together; and the presumably common inter-connect of all elements to national or international networks, such as the Internet.

Yet a third service provider may cluster MS-Os and a VSAT network hub at one common location, MS-Is and MS-Hs at another switching hub, and back-haul all telecommunications and Internet traffic to the MS-I/H hub. To this provider, the most important network elements are the market sites, the VSAT network, the MS-O/satellite hub, the MS-I/H hub, the interconnect between the hubs, and the nationwide telecommunications back-haul means.

The point of this short exposition is just that the network reference model is broad enough to allow a significant variation in physical implementations, and that each such implementation carries with it its own natural grouping of network elements.

Together, ReFLEX and WMtp support a wide range of network implementations, satisfying the needs of almost any service provider, big or small.

### Network Monitoring and Control

ReFLEX operators are data specialists experienced in operating high-quality reliable IP-based data networks. For the most part, network equipment is similar to that used by any Internet service provider. Hence, simple network management protocol (SNMP) plays a significant role in the element management process.

Most ReFLEX carriers operate a Network Operations Control Center (NOCC) 24 hours a day, 7 days a week. Such a center proactively monitors the entire network for fault and performance related issues and dispatches equipment and personnel when necessary. USA Mobility's NOCC is located at its corporate headquarters in Dallas and dispatches more than 250-network support and field engineers dedicated to maintaining network infrastructure.

## ReFLEX NETWORK COVERAGE

### U.S. Coverage

ReFLEX networks have the largest terrestrial-based U.S. wireless data network footprint of any kind. Existing ReFLEX networks cover 313 out of 315 of the U.S. Metropolitan Statistical Areas (MSAs), as well as a large number of smaller towns in areas categorized outside MSAs. The following table shows relative coverage footprints for the different wireless packet data networks.

### U.S. Packet Data Network Coverage Comparison

Network Operator	Protocol	U.S. Population Coverage
USA Mobility	ReFLEX	90+%
Verizon*	ReFLEX	90+%
Arch*	ReFLEX	90+%
USA Mobility*	ReFLEX	90+%
TSR*	ReFLEX	90+%
PageNet	ReFLEX	80%-90%
Motient	RD-LAP	80%
SkyTel	ReFLEX	70%
BellSouth Wireless Data	Mobitex	64%
Nextel	iDEN	66%
AT&T	CDPD	57%
AT&T	TDMA	>0%
Voicestream	GSM	>0%
Sprint PCS	CDMA	>0%

Source: Bear Stearns

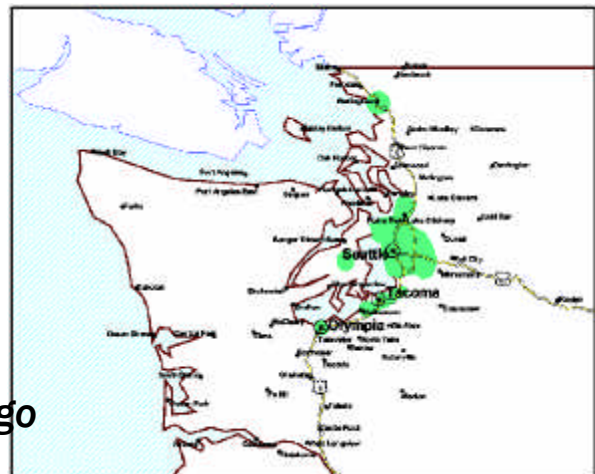
\*NOTE: Arch, AirTouch, USA Mobility, TSR and others use USA Mobility's network and are thus able to offer the same core

**Local Market Coverage Comparisons**

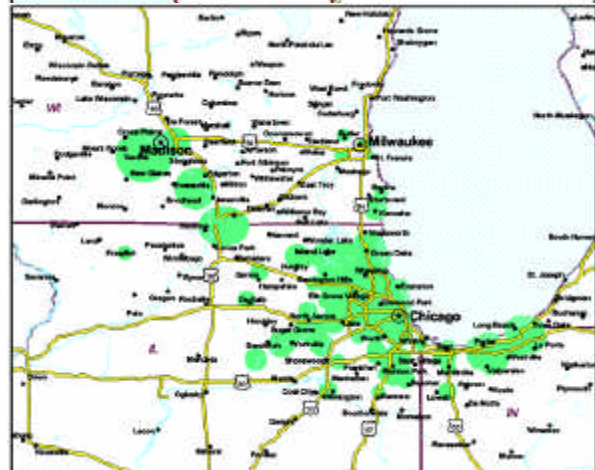
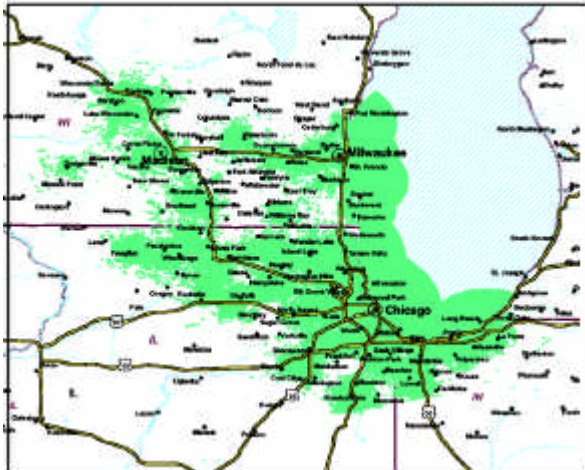
The following coverage maps, as advertised on the carriers' websites in July, 2000 illustrate the coverage comparison between the USA Mobility ReFLEX network and BellSouth's wireless data network for in-building coverage in several top MSAs.

**Seattle**

*footprint.*



**Chicago**



**USA Mobility**

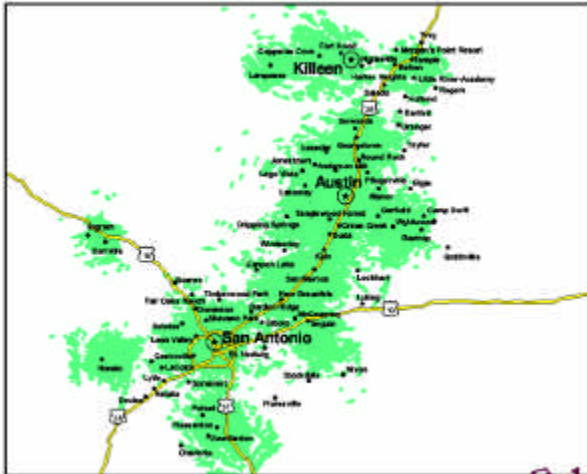
12,003 Approximate Sq. Miles for Full Service

**BellSouth Wireless Data**

4,080 Approximate Sq. Miles for Full Service

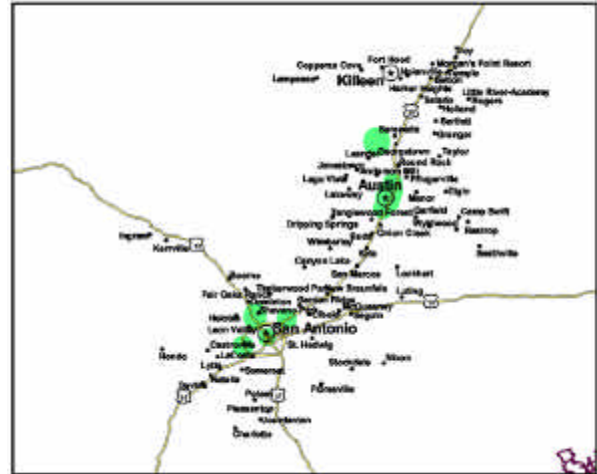


## Austin/San Antonio



### USA Mobility

4,986 Approximate Sq. Miles for Full Service



### BellSouth Wireless Data

395 Approximate Sq. Miles for Full Service

### International Coverage

One ReFLEX operator, USA Mobility, has assembled a wireless data alliance across North America with partners Bell Mobility in Canada and TelMex in Mexico.

Beyond NAFTA, USA Mobility's ReFLEX international goal is to provide reliable, seamless coverage in every major country throughout the Americas. Customers receiving messages in the United States will be able to roam automatically to other countries and receive their messages just as they would at home.

Through alliances with USA Mobility, ReFLEX wireless data coverage will likely be extended into the following additional countries in the future:

1. United States (operating networks since 1999)
2. Canada (planned for 2000)
3. Mexico (planned for 2001)
4. Peru (planned for 2001)
5. Brazil (planned for 2001)

6. Chile (planned for 2001)
7. The Bahamas
8. The Cayman Islands
9. Costa Rica
10. Colombia
11. The Dominican Republic
12. El Salvador
13. Guatemala
14. Haiti
15. Honduras
16. Nicaragua
17. Panama
18. Trinidad & Tobago



China and Japan have now announced their plans to deploy nationwide ReFLEX networks.

## REFLEX NETWORK CAPACITY

### Asymmetric Network Capacity

Much like Internet access applications DSL and ADSL, wireless data applications are not balanced in their capacity needs. Much more data is sent to a wireless device than is sent from the device. ReFLEX is unlike any of the other wireless data networks available today in that it can be optimized for asymmetric data rates.

In the United States, the FCC auctioned narrowband PCS spectrum in blocks of 50 kHz. A typical ReFLEX carrier may have two forward channel blocks of 50 kHz and one reverse channel block of 50 kHz, for a total of 150 kHz of bandwidth. Discontinuous 50 kHz blocks can support three ReFLEX FSK carriers on the forward channel and four ReFLEX FSK carriers on the inbound channel.

The industry's vision for ReFLEX involves a move to higher outbound data rates on narrower channels. The natural means to support this vision is the use of linear, multi-level quadrature amplitude modulation (M-QAM). The present view is that version 3.0 of ReFLEX will introduce these functions. Future upgrades to higher speed ReFLEX v3.0 M-QAM protocols will permit up to 14 outbound channels in a 50 kHz bandwidth. In this case, the total data rate on all frequency carriers would be in excess of 300 kbps per 50KHz, or a nominal 6 bps/Hz.

One of the major advantages of ReFLEX, and a major reason why the majority of the wireless data carriers chose to deploy this architecture, is ReFLEX is optimized for data and permits a carrier to deploy a uniform broad coverage nationwide network suitable for applications. ReFLEX provides the best architectural options to grow capacity as network use increases. Capacity can be quickly added when and where needed in key MSAs.

ReFLEX network operators have several alternatives for increasing network capacity as demand for services and network use grows. Most of the alternatives for growing capacity are borrowed from techniques used in

broadband PCS and cellular networks and do not require innovation in basic technology. All of these alternatives are available to ReFLEX networks and will be implemented as required. ReFLEX network operators long-term network and capacity management strategy envisions implementing these capacity expansions serially and selectively in the geographic areas in which additional capacity is required.

Following are some of the steps ReFLEX operators will take on a market-by-market basis if and when additional capacity is needed.

### Data Speeds, Forward Channel

ReFLEX network "outbound to device" capacity increases by increasing the forward channel speed. The forward channel speeds per 50kHz of frequency are as follows:

1. 25,600 bps (current) [0.51 bps/Hz]
2. 78,400bps (future) [1.57 bps/Hz]
3. 156,800 bps (future) [3.14 bps/Hz]
4. 313,600 bps (future) [6.27 bps/Hz]

Currently, ReFLEX networks have deployed the most current version of ReFLEX, version 2.6. Within the next 24 months, networks are expected to migrate to the next upgrade, version 2.7, which permits significant channel re-use. Following that, migration will move to the higher speed protocols (78,400 bps per 50 kHz channel) and multi-channel (14 per 50 kHz).

Since there's no such thing as a free lunch, the increase in forward channel data rate per carrier beyond 16 QAM requires the adaptive use of QAM to transmit long outbound messages to mobile units within the serving area of a single base station. ReFLEX will subsume the cellular-style, single-channel (non-diversity) Rayleigh fading forward channel, when the length of message warrants the choice. If the radio link will not support the higher bandwidth rates of the QAM channels, the message could be forwarded to the mobile using a fall-back to FSK with a dual-mode mobile (both FSK and QAM capable).

### **Data Speeds, Reverse Channel**

ReFLEX network “inbound from device” capacity increases by increasing the reverse channel speed. The reverse channel speeds per 50kHz of frequency are as follows:

1. 3,200 bps
2. 6,400 bps
3. 25,600 bps (current)
4. 38,400 bps (future)
5. Additional speed if required

Existing ReFLEX applications such as wireless e-mail do not require aggressive upspeeding of the inbound or reverse channel.

### **Installing Additional Transmitters**

ReFLEX network capacity can also be easily increased by installing additional transmitters at existing base station sites. When needed, the second transmitter (and additional transmitters) will be used and installed at existing sites to support additional channels and thereby to increase available capacity. ReFLEX operators will install additional transmitters only in sub-zones in which network use is highest, permitting effective nationwide network capacity to be increased with a relatively modest capital investment.

### **Sub-zoning**

Another important way to increase ReFLEX network capacity is to implement greater frequency re-use by sub-zoning within an Ms-H or simulcast zone. This increases frequency re-use by reducing the size of the effective simulcast zones, similar to the approach used by cellular networks. Implementation of sub-zoning is a software reconfiguration of the network, and does not require any significant deployment of additional equipment, relocation of base stations, or any other significant capital investment. ReFLEX operators have sufficient frequency to provide enough independent channels supporting a high degree of frequency re-use among contiguous sub-zones. While ReFLEX networks can be sub-zoned down to single transmitter cells, such a configuration would lose much of the mesh network effect and in-building penetration

advantages of simulcast networks. In general, given the concentrated geographic distribution of subscribers, ReFLEX operators will increase overall network capacity nationwide by a factor of two to three times by using sub-zoning while retaining the benefits of mesh networking and in-building coverage through the simultaneous use of multiple transmitters.

### **Installing Additional Receivers**

A ReFLEX operator’s inbound capacity can be increased by installing additional receivers at existing base station sites. ReFLEX operators can easily install multiple receiver cards in existing receiver cabinets. As a result, ReFLEX operators can also easily add additional receivers to permit operation of the additional reverse channels. ReFLEX operators can install more receivers only in those sub-zones in which network use is highest, permitting nationwide network capacity to be increased in a deliberate, cost effective manner. ReFLEX operators can also increase overall network capacity nationwide proportionally by installing additional receivers in high-traffic sub-zones.

### **Increasing Site Density**

As is common in the cellular industry, ReFLEX operators can further increase the capacity of its ReFLEX network by increasing base station site density, thereby attaining greater frequency re-use by reducing the size of each sub-zone. Increasing site density requires additional capital investment, as well as significant network re-engineering. ReFLEX operators will undertake this step only in those areas in which the requirements for additional network capacity are greatest, permitting effective nationwide network capacity to be increased by reconfiguring only a relatively limited portion of the network.

### **Spectrum Availability**

More spectrum has been licensed for ReFLEX deployment – more than 2 MHz – than for any other dedicated wireless packet data network in the United States. Additional narrowband PCS frequency is available and expected to be auctioned in the future.

## SUMMARY/CONCLUSION

ReFLEX based wireless data networks have demonstrated compelling benefits in terms of geographic coverage, in-building penetration, and the ability to support reliable delivery in difficult environments. Software based capacity increases will serve to maintain the cost advantage of this technology, which will be further consolidated through the development of the next generation protocols. As a result, ReFLEX based wireless applications have the greatest potential to dominate those based on other packet data protocols. In particular, wireless instant messaging, wireless e-mail, wireless e-commerce, and similar narrowband data applications will be positioned for major market success by the convergence of networks deployed by multiple operators, innovative devices offered by multiple vendors, and the performance advantages that the protocol supports. ReFLEX will be the protocol of choice for the next generation of wireless data messaging applications.

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This paper contains predictions and forward-looking statements involving risks and uncertainties that make the predictions and forward-looking statements subject to change. Such factors as unforeseen economic, market and technological forces could ultimately make the predictions and forward-looking statements incorrect.

## THE AUTHORS

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*N. Ross Buckenham*



*Allan Angus*

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v2 July 29, 2004