ReFLEX™ Wireless Data Technology

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

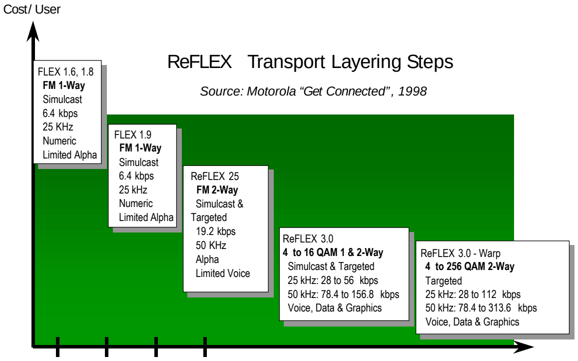
The ReFLEX protocol is uniquely engineered for reliable delivery of wireless packet data. ReFLEX has been selected by more carriers as the industry standard platform for light and medium wireless data load applications, such as e-mail, instant messaging, e-commerce, GPS locating, and Internet information 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[1]. 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.

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[2]. 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[3] than those employed in cellular or wideband PCS protocols. In contrast to cellular air interfaces, ReFLEX employs a much more complex simulcast channel[4], 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

[1] 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.

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

[3] 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.

[4] 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[5]. 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[6]. 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

[5] 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.

[6] 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.

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