Operations Brief
MinionNet™ Network Technology

The MinionNet™ Network developed by AFX TraTech, Inc., is a wireless data network characterized by short-range device-to-device messaging. Messages are automatically routed through multiple device-to-device 'hops' to provide robust area coverage, redundancy, noise immunity and dynamic routing and reconfiguration.

The devices used by the MinionNet™ Network are referred to as Minions and are actually extremely inexpensive two-way data radios. The key feature of these Minions are that they are able to share short data messages with each other. Each Minion becomes a part of a community and can share the burden of conveying messages throughout the area.

This concept is in stark contrast to all traditional network concepts which require the installation of an expensive fixed infrastructure prior to the operation of the network. Cellular phones, for example, require that every subscriber phone communicates only with the cellular base station. Even though there may be thousands of actual phones in the area, they are not capable of communication with each other. The ability to use short-range messaging between devices such as this has been ignored because of a perception that robust real-time connections are required by the expectations of consumers. Since the Minion Network is a data network for device-to-device messaging without a time-critical component it is able to leverage these capabilities into new applications.

Virtual Geolocation

The initial application of the Minion Network is to establish a Virtual Geolocation infrastructure for use by AFX TraTech's **cap**™ Certified Collateral Protection System. The **cap**™ System provides mobile equipment finance companies with exception reports concerning unusual movement patterns of financed vehicles.

Many 'tracking' applications such as this can actually be best addressed by a system that provides a general view of the location and movement of items without the expense of traditional precision location technologies such as GPS.

A Virtual Geolocation system provides 2-dimensional (or 3-dimensional) relative position information that is only loosely associated with absolute latitude and longitude (and altitude). Some applications will be adequately served by 'virtual addresses' alone, while others will need tighter correlation with actual physical positions. The Minion Network anchors a small number of points in the network with GPS-derived positions or known locations such as street intersections or floors of a building.

Nearby devices need only receive messages from these fixed points to have an approximate idea of their own location. With each 'hop' from device-to-device the area of possible position increases and the position accuracy degrades. The Minion Network is designed to automatically keep track of the count of 'hops' involved. The presence of multiple anchor points, and the use of the 'hop count' to approximate relative distances allows the Minion Network to approximate the actual position with the least expensive possible hardware. The use of short-range transceivers actually improves the resolution of this approach, as well as keeping the power requirements for each device to a minimum. This not only reduces costs but eases certification and environmental concerns.

Wide Area Minion Network Extensions

Just as certain points in a geolocation network need to be anchored to associate physical locations with virtual ones, other points in the network should be connected to a wider area network so that message travel times and network loading are minimized. This is accomplished by adding Mobitex® transceivers to a small percentage of the Minions in the field. These MobiMinions™ act as concentrators for messages bound to and from the centralized supervisory components of the nationwide Minion Network.

The dynamic configuration and automatic routing aspects of the MinionNet™ Protocol cause these messages to be routed by the most efficient method from their origin to their ultimate destination.

Basic Radio Protocol Features

The messages handled by the Minion Network can be thought of as being 32 bytes long and transferred at 9600 baud. Each Minion has a unique 32-bit serial number assigned during manufacture. This gives over four billion numbers, although number reuse is not as big an issue in this environment as it is in some others. Each message will contain space for four of these serial numbers: (1) the message originator, (2) the message final destination, (3) the device actually transmitting for this hop and (4) the intended receiver for this hop. Messages also contain a set of standard fields for message type codes, device status bits, message priority and handling bits. A payload area will contain application specific data such as geolocation information, time/date, etc., as determined by the message type codes. In addition, the protocol specifies a cyclic redundancy check (CRC-16) and an error correcting code (ECC) pattern used to correct single-bit errors encountered during transmission. The message length and data rate combine to give a maximum of 20 messages per second to or from a single node. The normal operation of the network will tend to keep the actual rate down below one message every few seconds. The actual radio modulation scheme provides easily detected balanced modulation with self clocking data bits. This allows wide variations in microprocessor clock performance with temperature and eliminates the need for a crystal oscillator.

The protocol is completely connectionless and each message is treated as an independent datagram. Protection mechanisms are built in to ensure robustness, but delivery of any individual message is not guaranteed. The database server may initiate enquiries into the distributed network and ask for retransmission of suspected missing messages.

The purpose of certain applications is to detect missing items and generate an exception report or alarm. Much useful information may be derived from interrogating the message routing tables of nearby nodes to establish the last known location.

The transceivers are half-duplex devices (they cannot transmit and receive at the same time). Several methods are used to avoid collisions (two nodes transmitting at the same time and garbling the message for the recipient). First, not all collisions will result in message corruption. If the receiver is not 'in range' of both transmitters it is unlikely that the message will be corrupted. Second, the level of traffic will be kept low and interval randomization techniques will be used to reduce the likelihood of simultaneous transmissions. Third, all messages are implicitly acknowledged when they are forwarded on the next hop, and explicitly acknowledged when received at their ultimate destination. Automatic retransmission and elimination of duplicate messages are features of the protocol.

The antennas for the radios are built into the case and are intended to provide omni-directional coverage. This will never actually be the case and environmental limitations are an expected part of the operation of the network. The operating range of any transceiver will not be a fixed distance but should rather be viewed as a probability function. Thus, the likelihood of successfully exchanging messages between radios is a function of their position in space. Viewed in this way, all sources of transmission error can be incorporated into a single function. This is similar to taking the bit error rate allowed for a fixed length message and determining the probability of successful reception. Unlike the wired network, the wireless network has a spatially distributed error rate.

That being said, think of the effective range of a Minion as varying from 100 to 300 feet.

Normal Operation Overview

The discussion that follows describes a normal operation situation such as might be encountered in support of the **cap**™ Certified Collateral Protection System. All operating parameters such as the interval between transmissions, the power consumption of each device, the number of devices and the level of network traffic are dynamically adjusted to fit the application and environment. The numbers given below is intended to provide a representative view of a possible implementation.

Consider the sample situation depicted in Figure 1. The local network consists of 18 Minions, each able to communicate with at least one other as indicated by the connecting lines.

These lines are not intended to indicate adjacent nodes, and indeed in some cases connections may be established over unusually long distances. This represents the possibility of favorable geometry and low radio background noise that may be encountered. In contrast, some physically nearby Minions may be unable to establish direct connections because of adverse environmental conditions, such as indicated by the brick wall.

Again, the network has no *a priori* knowledge of the location or connection paths available. The messages sent by the Minions themselves and the operating protocol allow this information to be dynamically derived.

Each node in the diagram represents a Minion with a short-range radio transceiver, a microprocessor and a small amount of memory. The labeled nodes have additional hardware that results in added functionality throughout the network. Even the least capable Minions will be able to make use of the features of the more capable devices nearby.

The nodes labeled 'A', 'B', and 'C' represent GeoMinions™ and act as anchor points for the Virtual Geolocation system. Each is equipped with a GPS receiver, or has been installed at a fixed point with known coordinates to act as a static beacon. The nodes labeled 'D' and 'E' are MobiMinions™ and have Mobitex® transceivers which allow direct connections to the Network server and database facilities.

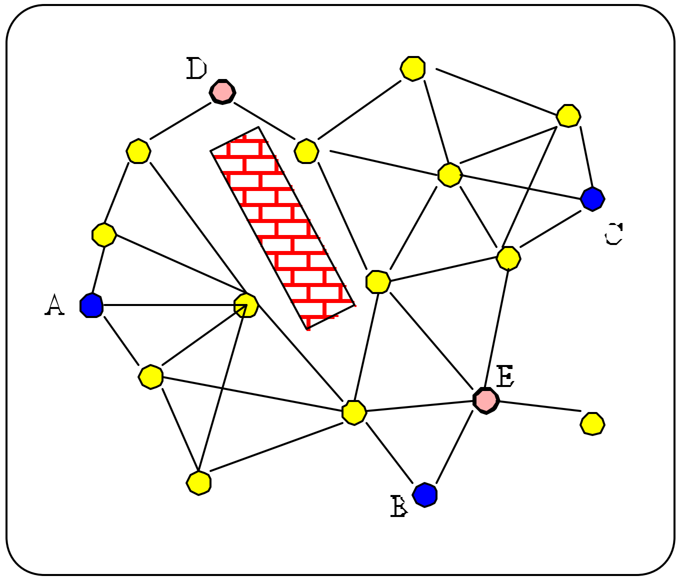

Figure 1
Sample Minion Network

On a periodic basis each MobiMinion™ will send out a broadcast message identifying itself and indicating that it is capable of sending and receiving messages to the central database server. This occurs on a random basis a few times per hour. Each Minion that receives the message remembers the number of the MobiMinion™ and adds it to a list of candidates to handle traffic destined for the database server. After an interval the message is transmitted on a second hop with an incremented counter. The message now means "I am a minion that is one hop away from a MobiMinion™, and I can handle your messages." The recipients of this message make note of it and send one that says "I am two hops away..." Obviously, nodes that have already heard about this Mobi-Minion™ will have smaller hop counts stored in their table and will ignore these later messages which are only proclaiming longer paths than they already know about. A network parameter controls the maximum number of hops allowed so that the proliferation of messages from distant sources will be controlled.

In this manner, each Minion will have built a list of all of the nearby MobiMinions™. The number of hops required and the identity of the Minion to use as an intermediary will also be known. Thus, sending a message to the database server is accomplished by looking up the identity of the MobiMinion™ with the smallest hop count and sending out the message to the appropriate intermediary.

Once a Minion has discovered a valid way to contact a MobiMinion™ it will do just that. At random intervals (think several times per day) each Minion will send a message to its 'nearest' MobiMinion™. This message is basically just a status report and is buffered with others in the MobiMinion™. After some interval, and dependent on the desired traffic level on the Mobitex® network, these status messages will be forwarded to the database server via the wide area network. The purpose of these status messages is two fold: (1) the database server gets a 'heartbeat' from each Minion and knows how to address Mobitex® traffic destined for any particular Minion, and (2) each Minion involved in handling intermediary hops of status messages has seen routing information to allow a 'reply' to be delivered.

In this context a 'reply' to a status message could be any message from a MobiMinion™ to another Minion. Remember that this is really a connectionless protocol and that all messages are really datagrams.

It would be possible for the database server to originate a message for a particular Minion at any time, but the chances of its successful delivery are greatest just after a status message has been sent by the Minion. This assumption allows us to maintain very short history tables in each Minion. Perhaps only a few dozen entries would be needed to provide thoroughly effective delivery if only the most recent information is kept.

The same philosophy of communicating in multiple hops and retaining records in each Minion can be extended to the Virtual Geolocation application.

Each of the GeoMinion™ nodes (‘A’, ‘B’ and ‘C’ in Figure 1) periodically sends out a broadcast message with its current GPS position. As this message is forwarded from node to node the position and number of hops is recorded by each Minion. After data has been collected from several GeoMinions™ it is possible for each Minion to compute a weighted average position based on the relative distances from each known location implied by the hop counts.

This is an example of the benefits of using short-range radios in the Minion Network. Short range coverage means better resolution for position estimates. Wide area networks require sophisticated and expensive time delay or time of arrival measurement equipment to accomplish similar results. This equipment is so bulky and expensive that it can only be installed at fixed base stations. In addition, position information using time of arrival data can only be derived if the target unit is in the coverage area of multiple base stations.