APPENDIX G   USE OF BEACONS FOR WIDE AREA DELIVERY/COLLECTION OF ITS INFORMATION

G.1 Introduction

In the ITS architecture, certain ITS interconnections are handled by means of wide area wireless communication systems such as cellular, while other services are handled by short range wireless links such as dedicated short range communications (DSRC) systems or beacons. It is important to chose the communications technology appropriate for each application. It is also worthwhile to observe that ITS has a number of new applications for each technology that will expand the use of existing infrastructures. Significant attention has been paid to the wide area technology elsewhere in this document. This section focuses more on the dedicated short range communications. The broad collection of messages specific to this interface is summarized in table G5.1.

The first type of interconnections, wide area wireless communication systems, supports several service groupings which include:

- traveler and driver information (e.g., routes, yellow pages information, emergency services)
- commercial vehicle operation – local and long haul (e.g., routes, dispatch, preclearance, yellow pages, emergency services, vehicle and cargo tracking)
- emergency vehicle management (e.g., dispatch, routes, status reporting)

The second type of interconnections, short range wireless links, support services that include:

- public transportation management (e.g., fixed route and paratransit management, emergency services, fare and passenger load management)
- toll collection
- roadside safety inspection (e.g., roadside check and safety check)
- in-vehicle signing (e.g., fixed signage beacons, incident warning beacons)

Message structure, traffic loading, and performance have been analyzed elsewhere in this document for the first type of interconnections under the proposed cell-based architecture. However, the partition of user services between wide-area and short-range wireless communication is not uniquely determined by (technical) system requirements.

In the communications analysis, messages are allowed to flow over the wide area (u1t) interface and the dedicated short range (u2) interface. A determination of the fraction that may flow over each interface was also made. The assignments are detailed in Section 4.5 of this document.

Table 4.5-1 lists the messages and the interface(s) that each is allowed to flow over. This table was primarily developed in order to model the u1t interface loads, and therefore was designed for the worst case analysis for that interface. This means that the ratio of u1t to u2 data loads was kept high, and u1t data loads were maximized by assuming that the use of the u2 interface does not, in many cases, reduce the u1t data load. This was done in order to model the worst case situation where no beacons are deployed.

The purpose of this section is to examine, primarily from technical and feasibility standpoints, alternative architectures in which some or all of the services in the first category are provided by short-range wireless communication between vehicles and roadside beacons, i.e., wide area coverage by means of roadside beacons. The specific beacon system considered here just as an example is Hughes' DSRC system.

Three technical issues will be examined quantitatively, based on traffic loading analyses which have already been performed. These are: 1) compatibility of message formats with Hughes' signaling format used here as a working example; 2) the impact of DSRC data traffic on the wireline network; and 3) most importantly, the crucial issue of coverage and the related problems of delay and complexity. Conclusions will then be drawn, from a technical perspective, regarding the utilization of short-range communication systems (beacons) in the ITS architecture. This will be followed by an analysis that touches upon the economic considerations of wide area deployment of dedicated beacon systems.

G.2 Candidate Beacon Deployment

All beacons in the metropolitan area are assumed to use the same frequency, and beacon placement is constrained by the need to eliminate interference. In the DSRC system, receiver sensitivity is set to limit the effective range to about 200 feet. For acceptable interference levels, the minimum separation between beacons in the absence of obstructions is about 1/3 mile. This leads to the deployment shown below using cross-hatched circles. In an urban or suburban setting, however, the obstruction caused by buildings located on a rectangular street grid allows placement of additional beacons without interference. Typically the number of beacons can be doubled by locating the additional beacons (shown as dotted circles) equidistant from the original ones. We therefore postulate the idealized full deployment of Figure G.2-1.

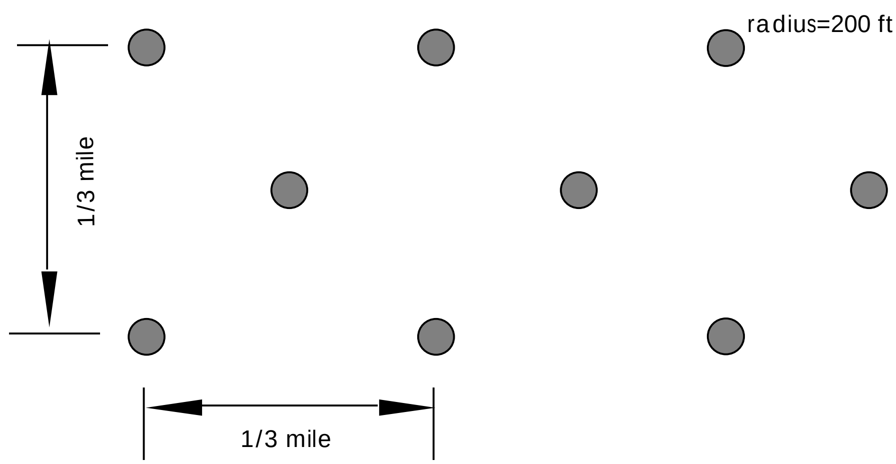


Figure G.2-1 Full Deployment of a Beacon System

In this deployment, there are eighteen beacons per square mile. Since the Urbansville region covers 800 square miles, the postulated deployment would require approximately 14,400 beacons. The postulated full deployment of DSRC would greatly increase the number of devices which must be installed along roadways and connected via wired communication networks relative to a cellular wide area solution, and would thus increase the initial costs associated with communication infrastructure deployment.

Another key aspect of the indicated deployment is that the fraction of the total area actually within communication range of a beacon is just $18 * \pi(200)^2 / 5280^2 = 0.081$ (8.1%). However, given that the vehicles move essentially on surface streets and highways, it is more meaningful to compute the percentage of “linear” coverage, i.e., the fraction of the roadway length covered by the beacons. The fraction is slightly higher at 200 / (5280/3) = 0.114 (11.4%). This immediately points out to the fact that only a small percentage of the vehicles will be within range of such a fully deployed system.

This possible coverage could be increased if frequency reuse were implemented, since beacons operating at different frequencies could be interspersed among those shown above. Such a system would then be no different from a full fledged micro-cellular system-- and if implemented on a wide scale as in the case of cellular telephone systems, would be prohibitively expensive for any dedicated set of users . Such a hypothetical situation, however, would defeat the essence of DSRC, which is based on site specific information exchange. Thus, it will not be considered.

G.3 Message Compatibility with DSRC

Again we consider here the open system specification proposed by Hughes as an example of a DSRC system capabilities. The Hughes system uses TDMA with a reservation slotted-ALOHA access protocol to resolve collisions that result from multiple vehicles responding to the trigger of the reader. The TDMA protocol has a basic frame length of 9.58 ms (including guard and dead times) during which the reader and transponders communicate. The frame consists of three segments. The first is the segment where the reader sends a control message to activate the transponders and/or give them instructions. The second segment is the data message segment containing four slots each of which can be used for either forward or reverse transmission of a data packet under control of the reader. The size of these packets is 512 bits. The third segment is the one in which transponders respond to the reader's trigger with their respective ID's.

The message lengths which have been defined in the ITS architecture to be sent over the u2 interface for various wireless ITS services are generally less than 500 bits. (See Table G.5-1 for a listing of the messages.) Hence, the majority of ITS messages will be compatible with a single 512 bit slot in the DSRC TDMA format. In some cases, messages may include larger amounts of data that will significantly increase their length. However, these messages can be accommodated either by multiple slots within a frame or multiple slots in successive frames.

G.4 Impact of ITS Data on Beacon Capacity

The effective user data rate of a beacon (on the order of 200 kbps) is much greater than that of a mobile wide area wireless channel (e.g., a CDPD channel with a 19.2 kbps channel rate). In addition, a beacon will serve fewer vehicles than a cellular sector. Therefore, data throughput of a DSRC is adequate to support ITS wireless traffic from vehicles within its limited range (100 to 200 feet).

G.5 Impact of DSRC Traffic on Wireline Network

If wide area wireless communication is based on beacons rather than cell-based techniques, additional communications loading will occur on the wireline network connecting beacons, hubs and TMCs. In a cell-based architecture, wide area mobile communications are provided by wireless carriers, so they do not contribute to this wireline traffic. If cellular communications were replaced by widely deployed beacons, some of this wireless traffic would also have to pass through the ITS wireline network.

Many beacons may be placed along highway rights of way and then be able to utilize any private fiber network placed along that path to provide wireline communications with their controller.

The larger fraction of the total beacon population that is not along a fiber route will need to be connected to the beacon controller through additional wireline links. These will be assumed to be leased digital lines and will not impact the performance of any existing wireline network..

Table G.5-1 ITS Wireless Messages for the u2 Interface

PA Source	PA Sink	Logical Data Flow	Size (Bytes)
Basic Vehicle	PMS	fbv vehicle characteristics	6
Basic Vehicle	RS	fbv vehicle characteristics	6
Basic Vehicle	TCS	fbv vehicle characteristics	6
Commercial Vehicle	CVCS	fcv vehicle characteristics	6
CVCS	Commercial Vehicle Driver	tcvd clearance pull in output	64
CVCS	Commercial Vehicle Driver	tcvd general pull in output	64
CVCS	Commercial Vehicle Driver	tcvd safety pull in output	64
CVCS	Commercial Vehicle Driver	tcvd inspection results	32
CVCS	CVS	cv inspection data output	1024
CVCS	CVS	cv request on board data	32
CVS	CVCS	cv on board data	200
CVS	CVCS	cv electronic clearance data	48
EVS	RS	emergency vehicle preemptions	8
PMS	Driver	td parking lot payment confirmed	2
PMS	Driver	td parking lot payment invalid	2
PMS	VS	parking lot payment debited	1
PMS	VS	parking lot payment request	2
PMS	VS	advanced parking lot charges confirm	18
Potential Obstacles	VS	From Potential Obstacles	16
Roadway	VS	From Roadway	16
Roadway	VS	From Roadway	16
RS	Driver	td lane use indication	4
RS	Driver	td ramp state indication	4
RS	Driver	td signal indication	4
RS	Driver	td vms indication	8
RS	VS	vehicle signage data	20
RS	VS	ahs check response	513
TCS	Driver	td toll payment confirmed	2
TCS	Driver	td toll payment invalid	2
TCS	VS	toll payment debited	1
TCS	VS	toll payment request	2
TRMS	Transit Driver	ttd route assignments	64
TRMS	TRVS	transit operator request acknowledge	2
TRMS	TRVS	approved corrective plan	1024
TRMS	TRVS	transit vehicle conditions	2908
TRMS	TRVS	paratransit transit driver instructions	128
TRMS	TRVS	transit services for corrections	10240000
TRMS	TRVS	transit services for eta	10240000
TRMS	TRVS	transit vehicle advanced payment response	53
TRMS	TRVS	transit vehicle fare payment debited	1
TRMS	TRVS	transit vehicle fare payment request	2
TRMS	TRVS	transit vehicle fare data	113
TRMS	TRVS	request transit user image	8
TRMS	TRVS	other services vehicle response	293
TRMS	TRVS	transit services for vehicle fares	10240000
TRMS	TRVS	confirm vehicle fare payment	1
TRVS	Payment Instrument	tpi debited payment on transit vehicle	4
TRVS	Payment Instrument	tpi request fare payment on transit vehicle	2
TRVS	RS	transit roadway preemptions	16
TRVS	RS	transit ramp preemptions	16
TRVS	TRMS	transit emergency details	36
TRVS	TRMS	transit operator emergency request	256
TRVS	TRMS	transit user vehicle image	1024000
TRVS	TRMS	fare collection vehicle violation information	1024046
TRVS	TRMS	request vehicle fare payment	49

Table G.5-1 ITS Wireless Messages for the u2 Interface

PA Source	PA Sink	Logical Data Flow	Size (Bytes)
TRVS	TRMS	other services vehicle request	293
TRVS	TRMS	transit vehicle passenger data	28
TRVS	TRMS	paratransit transit vehicle availability	1
TRVS	TRMS	transit vehicle fare payment confirmation	1
TRVS	TRMS	transit vehicle advanced payment request	283
TRVS	TRMS	transit vehicle location for deviation	32
TRVS	TRMS	transit vehicle location	32
TRVS	TRMS	transit vehicle arrival conditions	128
TRVS	TRMS	transit vehicle schedule deviation	32
TRVS	TRMS	transit vehicle eta	27
TRVS	TRMS	transit vehicle deviations from schedule	32
TRVS	TRMS	transit conditions request	2
TRVS	TRMS	transit vehicle collected data	0
TRVS	TRMS	transit emergency information	36
TRVS	TRMS	transit vehicle location for store	32
Vehicle Characteristics	PMS	From Vehicle Characteristics	1000000
Vehicle Characteristics	TCS	From Vehicle Characteristics	1000000
VS	PMS	parking lot payment confirmation	1
VS	PMS	parking lot tag data	15
VS	PMS	advanced parking lot charges request	74
VS	RS	vehicle status details	4
VS	RS	ahs route data	2401
VS	RS	ahs vehicle condition	128
VS	TCS	toll tag data	15
VS	TCS	toll payment confirmation	1

G.6 Some Problems with Beacon Systems

One of the serious drawbacks of wireless communication using beacons is transmission delays which occur while a vehicle is located in the dead zone between beacons. This is, of course, most significant for vehicles which are traveling slowly or are stationary for some period of time as illustrated in Figure G.6-1.

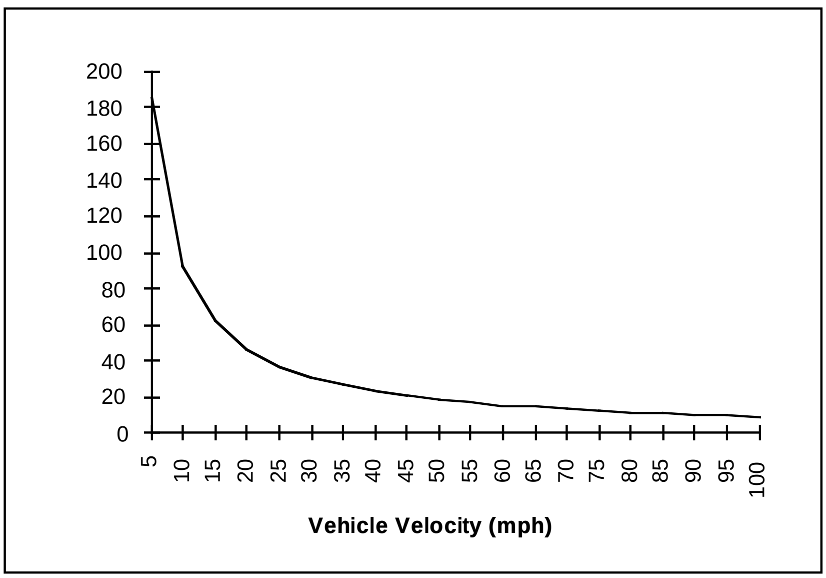


Figure G.6-1 Transmission Delay as a Function of Vehicle Velocity

For example, a vehicle traveling 10 mph requires 93 seconds to traverse the 1360 foot dead zone between beacons. This should be compared with the following list of requirements for round-trip transmission time:

Driver information	5 seconds
En route transit advisory	5 seconds
Route guidance	5 seconds
Incident management	1 second
Traffic control	5 seconds
Commercial vehicle pre clearance	5 seconds
Automated roadside safety inspection	5 seconds
Commercial vehicle administrative processing	5 seconds
On-board safety monitoring	5 seconds
Commercial fleet management	15 seconds
Public transportation management	5 seconds
Personalized public transit	5 seconds
Emergency notification and personal security	1 second
Public travel security	1 second
Emergency vehicle management	1 second

It is clear that a beacon system cannot meet transmission time requirements for many wide area ITS services under normal traffic conditions.

Another problem that surfaces with a wide area deployment of a beacon system is the complexity required to carry out two-way communications between the fixed center (ISP or TMC) and vehicles which move from one beacon to another during the exchange. The time a moving vehicle will remain in the coverage area of a beacon is plotted in Figure G.6-2.

For example, a vehicle traveling at 60 mph will traverse beacon coverage (400 feet) in 4.6 seconds. For many traffic types a query from the vehicle will elicit a response from either the TMC or a third-party provider. In many cases, the response will not be available until after the vehicle has left the coverage range of the beacon. Therefore, the TMC must direct its response to multiple neighboring beacons. Figure G.6-3 shows the number of beacons at which vehicles traveling at 60 mph might be located as a function of elapsed time assuming vehicle direction is known to the service provider within ± 90 degrees. Compensating for this location uncertainty will increase processing at the TMC or service provider and message storage at the beacons. In order to minimize wireless traffic, the beacon-to-vehicle communication protocol should restrict transmission of such responses to the first reader which establishes contact with the vehicle and transmits the response.

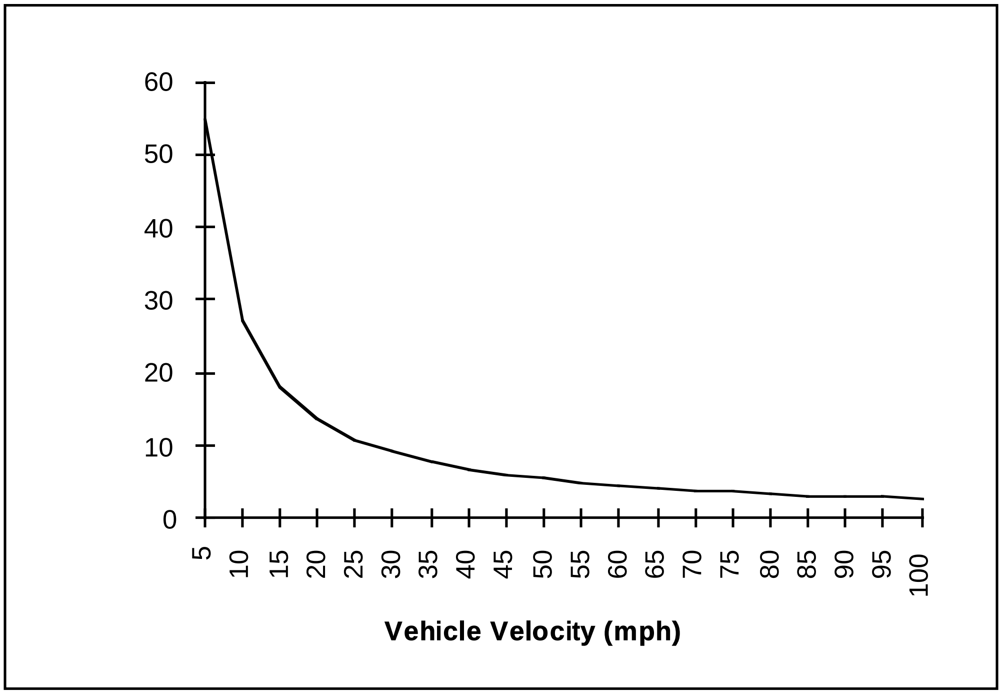


Figure G.6-2 Time a Vehicle will Remain in the Coverage Area of a Beacon

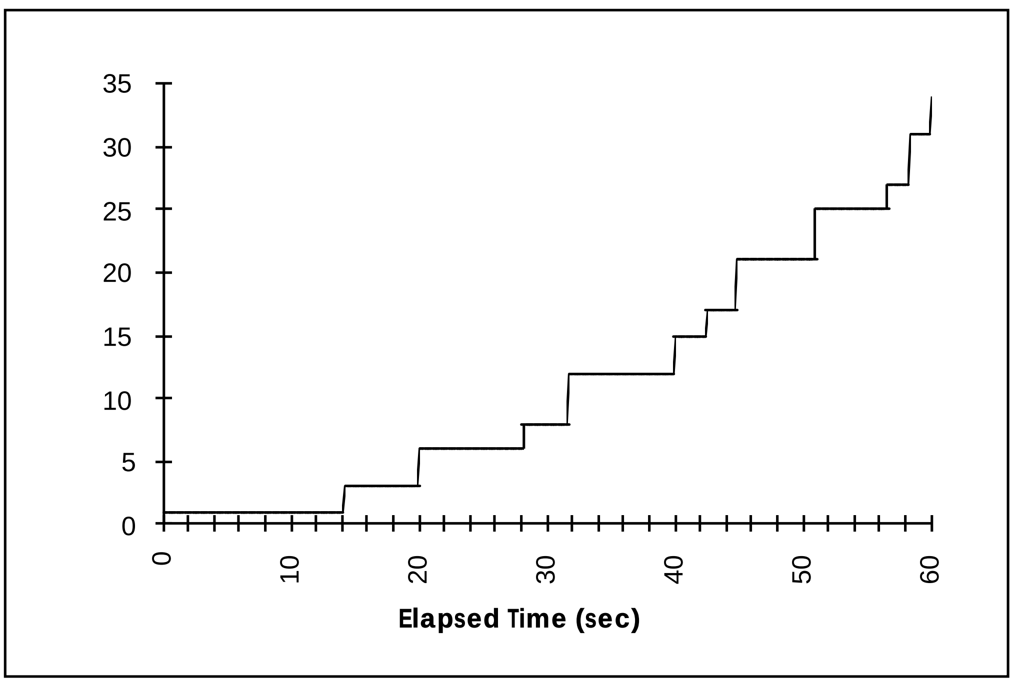


Figure G.6-3 Location Uncertainty (number of beacons at which vehicles traveling at 60 mph might be located at) as a Function of Elapsed Time

G.7 Summary

An evaluation of beacon systems in the context of providing wide area ITS communication services has led to the following conclusions:

- A widely deployed beacon system would be technically capable of accommodating projected ITS wireless communications traffic within its footprint. Such a beacon system would however be inadequate and inappropriate for all time-sensitive wide area services due to holes in coverage.
- A beacon system is appropriate only for specific short-range services, requiring only a limited deployment. This avoids issues of delay, complexity and above all cost, which arise in connection with a widely deployed system. Examples of short-range services for which beacons are suitable include toll collection, truck clearance at borders, and roadside inspection (see Chapter 3 for the full details).

APPENDIX H WIRELESS AND WIRELINE PROTOCOLS

H.1 Wireless Protocols

H.1.1 CDPD

The wireless protocols for the CDPD test case are described concisely as follows:

1. Media access protocol:
   – DSMA/CD in the reverse link
   – TDM broadcast in the forward link
2. Link access protocol: MDLP
3. Error control/correction protocol: RS-coding plus TCP/IP control
4. Transport protocol: TCP
5. Networking protocols: IP
6. Routing algorithm/tables: IP
7. Packet processing algorithm: SNDCP

H.1.2 CDPD Protocols as Implemented in MOSS

The data delivery air-interface platform which is implemented on MOSS, follows the Cellular Digital Packet Data (CDPD) reverse and forward links protocols. The following is a short description of the CDPD part in MOSS, which draws closely from the CDPD system specification[1].

In the forward link, MOSS implements a constantly transmitting Mobile Data Base Station (MDBS). By default, for a given base station and a given sector, MOSS randomly selects a single channel for CDPD use, out of the set of frequencies allocated to that sector under a given, most likely 3-sectored, frequency plan[1].

[1] The default frequency plan used in MOSS, which meets the Advanced Mobile Phone System (AMPS) specifications, is given in *Mobile Telecommunications Systems*, W.C.Y. Lee, McGraw-Hill 1989.

MOSS' CDPD forward link transmission information includes periodically two signals that inform the mobile users on the reverse CDPD channel status: a "Busy/Idle" flag and a "Decode Status" flag. The content of these signals is constantly updated and is made available to the user community every seven CDPD "minislots" (a minislot last 3.1msec approximately), i.e., every RS-Block, the "quantum" of information in the reverse link. Note that no other information (more specifically no ITS information) is transmitted to the users in the forward link.

The performance of CDPD equipped cellular infrastructure for a mix of voice and data users hinges on the combined performance of the Physical layer and the Medium Access Control (MAC) layer on top of it. The task of the Physical layer design is to control the interference induced by co-channel voice users in other cells through the use of power control and error correcting codes (ECC), in this case a Reed-Solomon (RS) (63,47) code. The MAC protocol, on the other hand, resolves contention on the common reverse channel due to the competition with the other data users within the same cell.

In the reverse link, MOSS implements the random-access protocol as described in the *CDPD System Specification*. At the Physical Layer, the implementation uses independently computed results regarding the decoding performance of a CDPD receiver that meets the specifications. The CDPD receiver uses a two-branch diversity scheme called Decision-Directed Phase Estimation[2]. The receiver makes maximum use of knowledge of the waveform structure, and of all the information made available by the system (e.g., the sync and continuity indications on the reverse link, and sync words and flags on the forward link).

At the MAC layer, MOSS follows all the details of CDPD reverse channel random-access protocol, which conforms to a non-persistent Digital Sense Multiple Access with Collision Detection (DSMA/CD) protocol. Parts of the Mobile Data Link Protocol (MDLP) which relate to the CDPD re-transmission policy are implemented as well.

The CDPD specification (see Figure H.1-1 and H.1-2) establishes the Reed-Solomon (RS)-block as the quantum of information transmitted in the channel. Thus, the transaction lengths determined elsewhere in this document have to be converted to the corresponding number of blocks, taking into account the overhead introduced by TCP/IP.[3] In its present form, TCP/IP adds 40 bytes (320 bits) of addressing and control overhead to the first packet of each transaction. If more than one packet (are required, significant header compression gain (from 40 to 3 bytes on average[4]) could be achieved. Industry consensus at this time is that four RS-blocks is the optimum length of a packet. In the ITS case, all the transactions analyzed so far require only one packet in each direction, so no gain can be achieved.

[2] Described in *Digital Communications*, J.G. Proakis, McGraw-Hill, 1983.

[3] A recent reference on this subject is *TCP/IP Illustrated- Volume I : The Protocols*, W.R. Stevens, Addison-Wesley, 1994.

[4] The definitive reference for header compression is "Compressing TCP/IP Headers for Low-Speed Serial Links", V. Jacobson, Network Working Group Request for Comments 1144, February 1990.

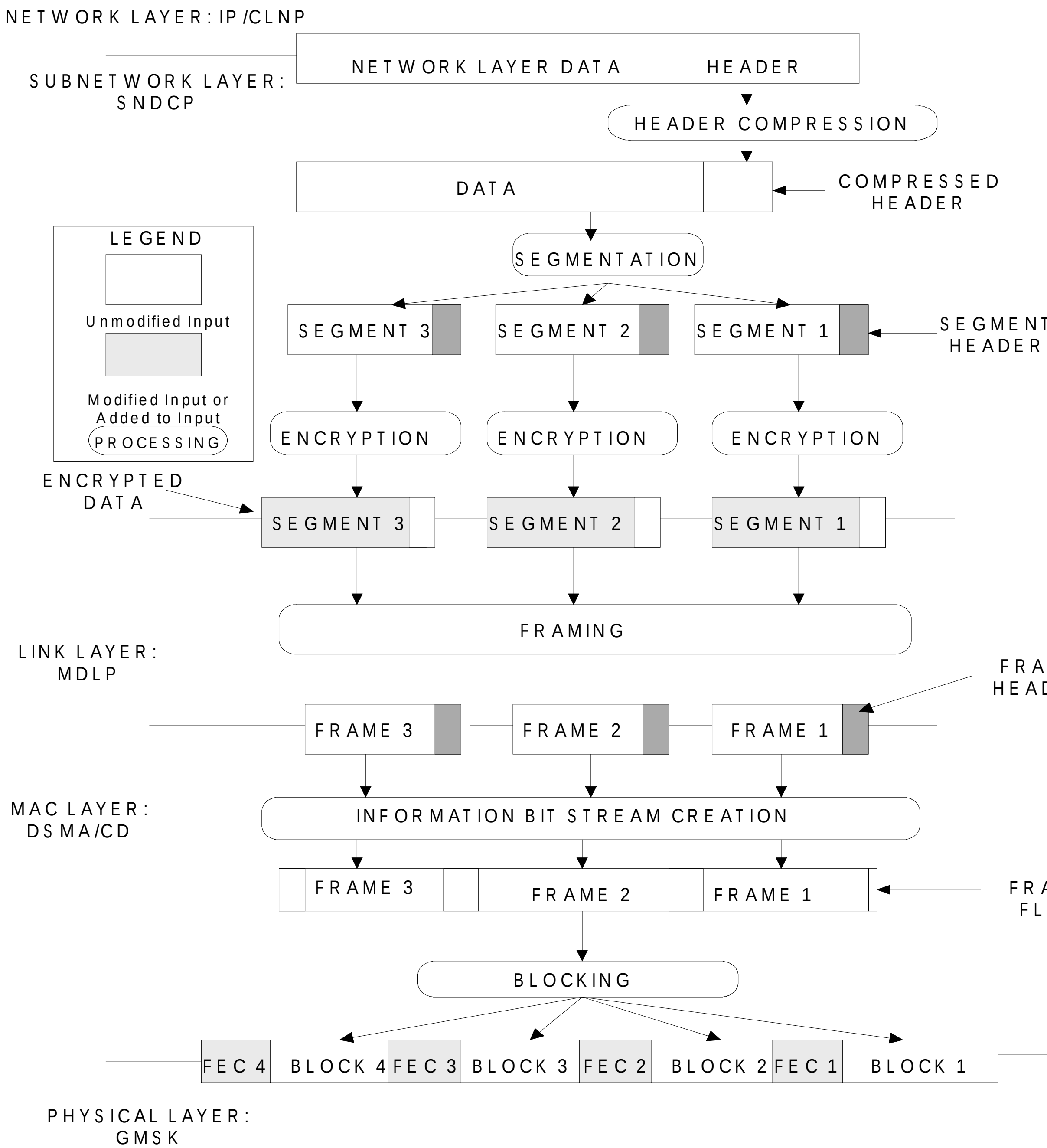
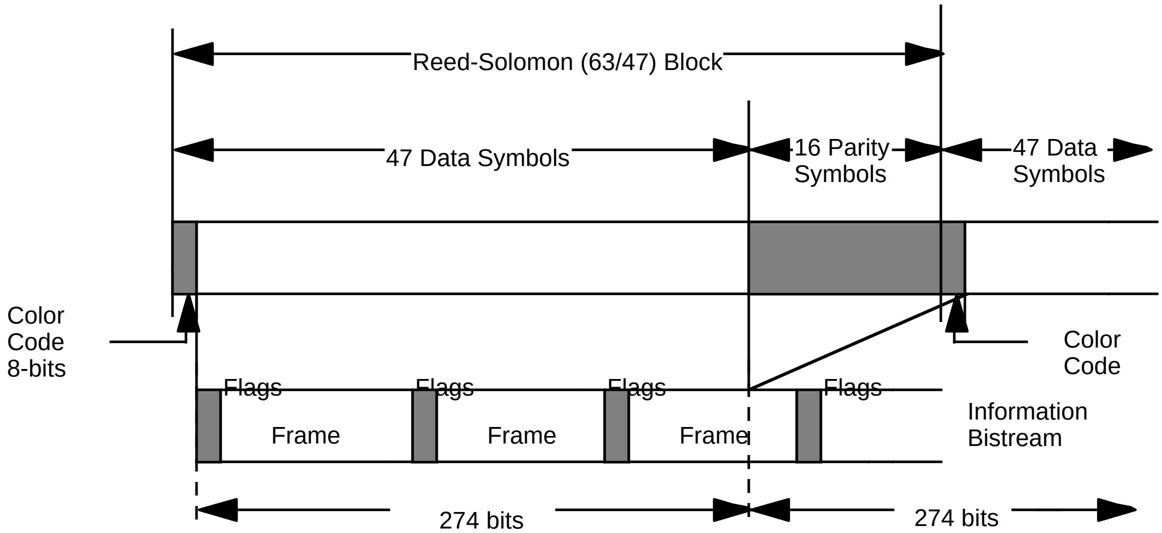


Figure H.1-1 Packet Segmentation in CDPD
(from CDPD System Spec-Release 1.0)

Forward Channel Framing and Block Structure



Reverse Channel Framing and Block Structure

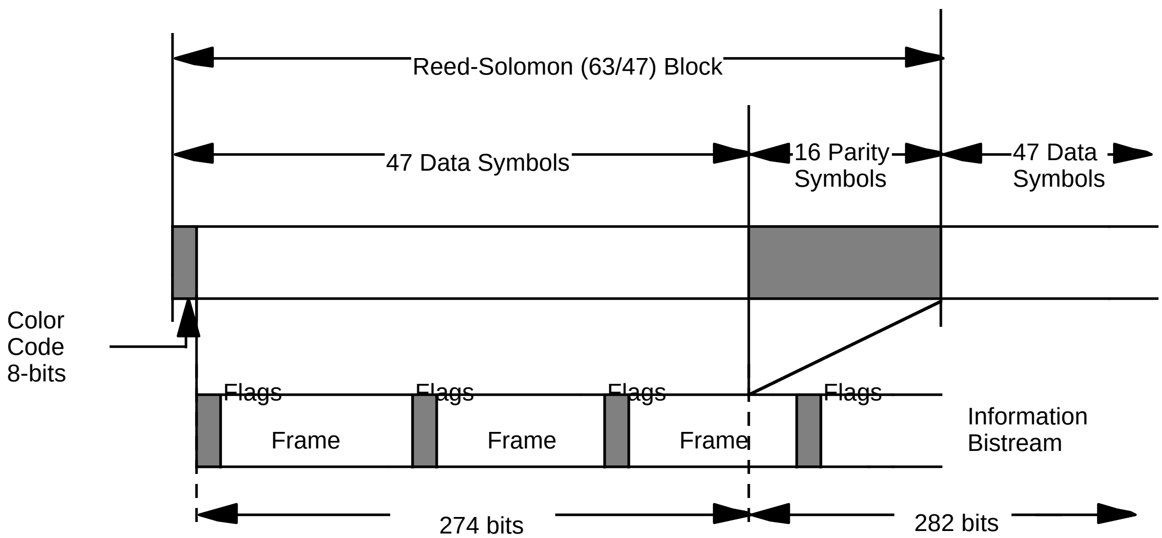


Figure H.1-2 Framing and Block Structure for CDPD (from CDPD System Spec-Release 1.0)

H.1.3 GPRS

As soon as the information becomes available (i.e., as soon as the standard work at ETSI moves to a no-proprietary level), a brief, comparative description of the proposed protocol will be included.

H.2 Wireline Protocols

Whenever appropriate, the protocols in the supporting wireline component will be matched with those of the wireless segment. More specifically, TCP/IP will be used to direct the information coming from/destined to the wireless portion. For the interconnection of the fixed network entities (e.g., TMCs, TIPs, ERCs, sensors, signals, CMSs), a host of protocols, with a point-to-point emphasis, are available. A few protocols have been considered for the Data Collection and Control network, namely Ethernet-like, FDDI, and ATM/SONET. They are described below.

H.2.1 Ethernet

Ethernet is a bus-based local area network (LAN) technology commonly used today. Its operation is managed by a media access protocol (MAC) based on IEEE 802.3 standard. The role of this MAC protocol is to provide efficient and fair sharing of the communication bus connecting the stations in the LAN. The Ethernet MAC accepts data packets from a higher layer protocol and attempts to transmit them at appropriate times to other stations on the bus. However, because the higher layer protocols can forward data at any time and the bus is a broadcast medium, it is possible that several stations will simultaneously attempt to transmit resulting in packet collision. To resolve this problem, Ethernet's MAC protocol uses the CSMA/CD (Carrier Sensing Multiple Access with Collision Detection) scheme. This together with the “Truncated Binary Exponential Backoff” re-transmission mechanism promote Ethernet as one of the most powerful LAN protocols.

However, Ethernet has the following limitations when using fiber-based transmission for metropolitan-area communication between hubs and TMC in Urbansville:

- Ethernet is a coaxial-cable-based protocol. Therefore, electrical/optical (E/O) conversion is required as the interface between the optical signals transmitted and the electrical signals for processing.
- Ethernet is a LAN-based technology. For MAN application, such as our ITS architecture, the relatively large propagation delay will significantly degrade the system performance.
- Ethernet offers a typical data rate of 10 Mbits/sec. However, given that in our candidate implementation there are 6 Type-A and 3 Type-C hubs in Urbansville, each with 13 and 40 CCTV cameras, respectively, with each CCTV camera transmitting continuously at 64 kbits/sec, the total data rate required will be 12.672 Mbits/sec which exceeds Ethernet's nominal data rate. Therefore, Ethernet is not adequate to support this video traffic. A separate network for CCTV camera traffic would then be required.
- Ethernet cannot gracefully migrate to fully optical protocols such as ATM/SONET.

H.2.2 FDDI

Fiber Distributed Data Interface (FDDI) is a fiber-based medium access protocol for metropolitan area networks (MANs). The nominal channel transmission rate is 100 Mbps. Although a logical ring network topology is required, this protocol can support both physical star and ring topologies as in our ITS system architecture candidate implementations.

There are two types of traffic at each hub, namely, the constant-bit-rate traffic from the CCTV cameras and the variable-bit-rate traffic from various traffic controllers/sensors. In order to support both types of traffic, we use an enhanced version of FDDI called FDDI-II. In FDDI-II, the whole bandwidth (100 Mbps) is divided into 16 wideband channels (WBC) of 6.144 Mbps each. Each WBC can operate either in isochronous (circuit-switched) mode or asynchronous (packet-switched) mode. In our case, we assign an integral number of WBCs to the constant-bit-rate CCTV traffic and then use the rest of the bandwidth for asynchronous transmission.

H.2.3 ATM

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APPENDIX I SIMULATION TOOLS

I.1 Introduction

The data volume analysis was completed using a database model. A separate database form was defined to model each of the groups of user services studied. A total of seven groups of services were studied: Traveler Information, Freight and Fleet Management - Local, Freight and Fleet Management - Long Haul, Private Vehicle Information, Public Transportation Management, Emergency Management, and Probes. The other ITS service groups (Traffic Management, Vehicle Monitoring and Control, and Electronic Payment) were not studied here explicitly, but their relevant wireless data flows (e.g., vehicle probes) were included within other services studied. Traveler Information is defined as information for a traveler other than a driver. Freight and Fleet Management - Local includes all commercial vehicle services operating only within the metropolitan area. Driver information is reserved for non-commercial driver services. The Public Transportation and Emergency Management functions serve those two specific areas.

As mentioned in the *Architecture Evaluation Plan* document under simulation strategy, the ITS communication system simulation will be configured into two modules: wireless and wireline/backbone. Although the wireless segment typically limits performance, the joint performance is required for complete characterization and optimization of the communication layer of the ITS system architecture. GTE Laboratories' proprietary tools MOSS and GRANET will be used to model the wireless candidate technology implementations, and the commercial package OPNET will be used to simulate the wireline/backbone alternatives.

The wireless communication module simulates the communication between the vehicles and the serving base stations (BSs) through the air interface, covering all radio aspects, namely fading channel, frequency allocation, modulation scheme, transmitted powers, antenna patterns, and multi-access protocols. This, obviously, is only a segment of the overall connection between the vehicle and the fixed transportation entities such as the traffic management centers (TMCs), traffic information service providers (TIPs), or fleet management centers (FMCs). The wireless module would also evaluate the communication between the TMC and roadway sensors/actuators if these connections are wireless in some physical architecture renditions.

The wireline module simulates communication between the BSs and the mobile switching centers (MSCs — MD-ISs in the CDPD nomenclature), and provides as well the connectivity to and among fixed transportation entities (e.g., TMCs, TIPs, FMCs, regulatory agencies, and kiosks). The wireline network also provides connectivity between a TIP and a personal computer or cable TV user at home. Wireline is also likely to provide the connection between the TMCs and roadway sensors or traffic control signals. For the wide variety of fixed links and nodes identified herein the wireline simulation models link performance, processing at the switching nodes, and network routing protocols.

End-to-end (wireless and wireline) system performance will be obtained by feeding into the backbone simulation results derived from the wireless simulation. Dividing the communication simulation into the two separate modules has the following advantages:

- *Increases the programming and technical efficiency* — The wireless communication module uses cell-based (mobile) radio as the communication medium, while the "wireline" communication module uses either copper, optical fiber or fixed point-to-point microwave radio links. These two drastically different types of links (for fixed and mobile/portable users) have very different attributes and behaviors requiring distinct simulation capabilities and functions. In addition, the two modules, wireless and wireline, correspond to different mix of ITS user service traffic, with different traffic volumes, requirements, coverage areas, and with transport protocols that could well be very different. Partitioning the simulation into these two modules is therefore logical, and leads to enhanced utilization of specialized technical skills and programming efficiency.

- *Matches the strength of the simulation packages used* — The distinct transmission characteristics, communication schemes, and networking protocols require specific, highly developed simulation programs. A particular package (commercial or otherwise) typically does not provide an adequate simulation environment for both the wireless and the wireline communications. Partitioning the program into two modules allows us to take advantages of the strengths of the individual simulation packages.

It may be thought that the wireless and wireline communication modules should interact in real-time to simulate the end-to-end message transmission, for example between the vehicles and fixed entities like the TMCs, TIPs and FMCs. The wireless communication module would simulate how the packets are transmitted from a vehicle to a base station, and then the wireline communication module would take over the packets and simulates how a given packet is transmitted from the base station to the eventual fixed transportation entity. In the forward link, the fixed entity would, for example, answer the requesting vehicle or demand an update from it via the associated base station.

A close examination, however, reveals the following problems with a real time interface:

- *Incompatibility* — In general, integration of multiple commercial packages into a single interactive simulation requires heavy code translation and even code development. The increased overhead would offset any benefits resulting from the use of an integrated package.

- *Communication Overhead* — Large amounts of data would need to be transferred back and forth among the packages, significantly slowing the speed of the overall simulation.

Hence, in Phase 1, we consider off-line rather than interactive simulation with the following assumptions:

- The interaction between the wireless and the wireline communication modules occurs only as the data packet arrives at the base station and is delivered to the wireline communication module, or from the wireline communication module delivers a packet to the base station.

- The data packets suffer in the wireline portion of the communication system delays which are independent of those in the wireless portion, i.e., the delay distributions in the two segments are independent of each other.

The off-line interaction between the wireless and the wireline communication modules, i.e., between MOSS and OPNET, is as follows:

- The reverse wireless link simulation generates the input packet statistics for the wireline communication module. (Note : Voice is a factor in determining the wireless delay, but as soon as the data packets, ITS or non-ITS, reach the BS, it no longer affects the wireline behavior.)
- The wireline communication module, based on the data loading analysis and other market assessment derived inputs, generates the output packet statistics for the forward link simulation.

The packet statistics include the traffic matrix, the percentage of various traffic classes, the distribution of packet length, and the distribution of the packet inter arrival times.

The wireless communication module can be thought of as consisting of two wireless communication "sub-modules", one for each link: the up-link or reverse (i.e., from the vehicle to the base station) module, and the down-link or forward (i.e., from the base station to the vehicle) module. This division is convenient since different protocols are typically used on these two links. On the reverse link, many vehicles will share the same communication channel, and hence multi-access with collision-resolution protocols are used. In the forward link, on the other hand, the base station broadcasts messages to the vehicles, and thus a point-to-point protocol may be used.

The wireline communication module will simulate the data packet stream from the wireless communication by generating a packet arriving sequence with the statistics obtained from the reverse wireless module. On the other hand, the forward wireless communication module should simulate the data packet stream from the wireline communication by generating a packet arriving sequence.

I.2 Wireless Communications (Cellular/PCS)

The primary wireless communication simulation tools used are MOSS and GRANET, both GTE Laboratories proprietary software packages. The selected wireline simulation tool was OPNET, which was also used in conjunction with MOSS+GRANET for end-to-end performance analysis.

MOSS simulates the performance of mobile and wireless communication systems providing both voice and data services. It computes voice and data link and system aggregate performance figures. GRANET is a radio planning tool for Cellular and Personal Communication Systems which models the mobile propagation environment, the allocation of frequency channels, and the management of all the relevant detailed infrastructure and scenario information.

MOSS and GRANET have been developed based on years of experience with analysis, design and modeling of practical, deployed or soon to be deployed, state-of-the-art wireless communication systems. GRANET, for example, has been extensively used by GTE Mobilnet in the U.S. and abroad (Germany, Israel, Korea, Japan) for radio planning, and because of its capability to be tuned by field measurements, has performed consistently very well as a prediction/analysis tool in various GTE cellular service areas. MOSS, on the other hand, contains unique capabilities that combine in-depth analysis of wireless data packet systems (ideal for ITS) with the realism derived from validation with the measured behavior of operational cellular systems.

OPNET, the wireline simulation tool, on the other hand, is a widely used commercial product. It is very versatile and very powerful; an excellent match to the analysis required of the wireline network — with its myriad possibilities of mixing and matching technologies to meet the needs of disparate scenarios and jurisdictions. OPNET will be used to simulate the CDPD protocol stack beyond the radio link. Loral's CDPD protocol simulation will be integrated with GTEL's CDPD channel characterization to provide end-to-end CDPD delay, a much missed information in Phase I.

The combination of MOSS, supported by GRANET, with OPNET offers the Joint Team the ability to analyze, predict, and tradeoff the performance of the communication architecture, including both the wireless and wireline segments, and their interfaces.

I.2.1 Graphical RAdio Network Engineering Tool (GRANET)

GRANET is a radio planning tool for Cellular and PCS developed by the Mobile Systems Department of GTE Laboratories. This planning tool consists of a collection of software modules for the modeling of the mobile propagation environment, the allocation of frequency channels, and the management of all the relevant input/output information, which may include geographical data, antenna patterns, FCC forms, demographics, traffic, overlay maps, etc. The complete package may be used to engineer and optimize analog and/or digital wireless communication systems.

GRANET, which is graphics-based and highly interactive, is designed to run on UNIX graphics workstations with an X-Windows/Motif user interface. The radio propagation model that forms the core of this planning tool was originally developed to provide accurate AMPS and DCS-1800 radio coverage predictions. This model is based on extensive experimentation, and if necessary, can be easily tuned to specific areas. The AMPS frequency planning module is based on collaborative research carried out with Professor J. McEliece of the California Institute of Technology beginning in 1989. In addition, GRANET incorporates basic CDMA planning features based on radio engineering technology currently under development at GTE Laboratories.

GRANET has the capability to calculate and display:

- Coverage map – The maximum field strength among all cells serving the area.
- Best server map – This is a graphical display of the area served by each cell, i.e., the area for which the field strength contributed by a cell exceeds both a minimum service threshold and the field from every other cell.
- Interference diagram – The tool displays the ratio of carrier (best-server field strength) to interference (the total field strength contributed by all other cells using the same frequency group).
- Frequency planning – State-of-the-art algorithms have been developed for automatically finding optimum frequency allocation. These algorithms resulted from a research collaboration between GTE Laboratories and the California Institute of Technology. Some of the frequency planning display techniques were developed by GTE Mobilnet.
- CDMA planning – The tool can display maps of soft/softer hand-off regions as well as forward/reverse link availability.
- Comparisons with experiments – This feature is useful for tuning parameters of the PCS model using experimental data.

- Geographical information – Any of the above results may be overlaid on a variety of digital maps from the geographical database included with the tool. This type of information is provided for all of the US.
- Carey contours, necessary for FCC filings.

The planning tool is able to handle an arbitrary number of sites, configured as omni or sectored, arbitrary antenna patterns (horizontal and vertical), as well as arbitrary antenna down tilt. A powerful feature of GRANET is its ability to carry out traffic analysis using population databases and marketing inputs.

I.2.2 MObile Systems Simulator (MOSS)

The MObile System Simulator (MOSS) is a proprietary software package that has been developed at GTE Laboratories for simulating the performance of mobile and wireless communication systems providing voice and data services. Development of MOSS began in January 1991, with the following major objectives:

1. To simulate the behavior of cellular mobile radio systems on a macroscopic level;
2. To determine overall system performance given knowledge of the performance of its elements; and
3. To be able to easily study the performance impact of varying system parameters and deployment methods.

MOSS' objectives have been met in the form of a stand-alone modular C program which can be run on any UNIX workstation. MOSS models both the forward (base station to mobile terminal) and the reverse (mobile to base) links in a wireless communication system, and includes the effects of teletraffic statistics, large scale propagation effects such as log-normal shadowing and power loss laws, channel assignment algorithms, configuration of network elements such as radio ports and antenna sites, antenna gain patterns, and other details of the layout and configuration.

The core of MOSS is an event-list-driven discrete-event simulator designed specifically for simulating the behavior of mobile systems. The core module processes all events in the system, such as arrival and completion of service requests (calls and protocol data units), power control initiations, and vehicle motion. The software also includes data structures that define the system geometry, track and compile statistics for individual connections and traffic at individual base sites and for the system as a whole. These data structures include data on features such as: antenna gain patterns for each radio port, radio port placement and antenna sectorization, channels available at each sector, transmit power at each sector, and propagation characteristics in the system. Statistics on various aspects of system performance are collected and reported. Separate statistics are kept for forward- and reverse-link performance on each occurrence of service.

In the cellular voice mode, calls are modeled with Poisson arrival and exponential holding times, but arbitrary distributions for these quantities can be easily incorporated. In particular, the concept of a call has been generalized to apply to data packets, and statistics appropriate for arrivals and lengths of data packets in various applications can be used/computed.

Propagation loss is modeled using the Okumura-Hata equation $A + B\log10\ D$, where D is the distance in km, A is the 1 km intercept, and B is usually taken to be 3.46, which is a typical value encountered in cellular systems in urban environments. Log-normal variability of the received signal strength is taken into account by adding a zero mean normal random variable to the propagation loss, expressed in dB. Standard deviations of 6 dB and 8 dB are typically used. MOSS can model three levels of system interference: 1) co-channel only, 2) co-channel and adjacent, or 3) co-channel, adjacent and alternate.

Currently, MOSS incorporates simulation of AMPS analog cellular systems, IS-54 TDMA cellular systems, and CDPD packet data for overlay on voice cellular systems. Enhancement of MOSS to include facilities for simulating CDMA cellular systems is also under way. In addition, MOSS functions will be integrated with a GTEL-proprietary radio propagation analysis and prediction software tool, GRANET, which will be described below.

Specific features of MOSS include:

- Discrete event simulation of mobile/wireless systems.
- Determination of quality and performance statistics of mobile systems: voice quality, data quality, blocked calls, dropped calls or messages, average delay, etc.
- Simulation of analog and digital cellular voice systems and cellular packet data systems.
- Accommodates arbitrary cell/radio port geometry, arbitrary antenna gain patterns and transmit powers, and allows for arbitrary specification of traffic sources and distributions.
- Implements reverse link power control.
- Multi-channel CDPD capability: more than one CDPD data channel per sector.
- Enhanced mobility functionality
- Interface to the GRANET propagation prediction tool allowing for detailed radio signal strength maps for specific service areas to be used in place of the generic Okumura-Hata models currently used in MOSS.

Users are able to model their individual systems by selecting from various blocks of code to meet their own specifications. Performance is evaluated by examining the statistics generated, in particular C/I ratios and the number of calls blocked. Performance can be re-evaluated following selected changes to the system, such as using different antenna types, using different channel assignment techniques, modifying the frequency plan, etc. System evaluation is rapid – as an indication, modeling a 3 hour run at 10 Erlang of traffic, executing on an HP 9000/730 unloaded workstation, takes approximately 10 minutes. Raising the traffic level to 40 Erlang takes approximately 2.5 hours.

Development plans that will span 1995 and 1996 include addition of GSM and CDMA modeling capabilities to the existing AMPS, IS-54 TDMA, and CDPD packet data capabilities:

- Detailed link-level analysis and simulation of the performance of the GSM/DCS-1800 air interface – This effort will include modeling the effects of coding and interleaving in conjunction with a fully functional receiver employing maximum likelihood sequence estimation for optimal detection of the GMSK wave form in the presence of channel multipath. The model will also include the effects of antenna diversity and slow frequency hopping.
- CDMA packet data performance – We will make use of the CDMA modeling capability developed in previous years to explore various packet data schemes for use as an overlay on systems that providing voice services according to the IS-95 standard for CDMA cellular service.

I.2.3 Integrated GRANET+MOSS

As stated above, a modicum of integration between the two packages has already been achieved. However, it is still GTEL's purpose, independent of the National ITS Architecture effort, to proceed with the objective of full integration. The idea is to automate the use of the extensive mobile radio system simulation capabilities of MOSS with realistic propagation information obtained via GRANET (based upon topographical, topological, and land use information available through GIS data bases) made even more accurate via field measurement feedback, and not use MOSS' default Okumura-Hata model.

During Phase I, GRANET was used to obtain very realistic scenario propagation data for Detroit based upon topographical, topological, and land use information available through GIS data bases. Feeding this information into MOSS resulted in a rather tedious task which is currently being automated.

In Phase II, two other regions are being considered, corresponding to the Thruville and Mountainville scenarios, namely the Philadelphia-Trenton corridor, and Lincoln County, Montana. At this time, only coverage information is available, based upon information lifted from the operating cellular companies' FCC filings. Additional analysis using MOSS will have to be postponed until more complete, better information on the cellular deployment in those two area is obtained.

I.3 OPtimized Network Engineering Tools (OPNET)

Commercial simulation packages are usually designed for special types of problems, and their performance varies. The choice of OPtimized Network Engineering Tools (OPNET) as the simulation package for the wireline communication simulation stems from the following strengths of OPNET:

- A variety of library programs – OPNET addresses all the related levels of digital communication networks, including network architectures, node structures, protocols, data transmissions, and operational environments. A variety of library model programs, particularly those of wireline communication networks, are included in this package.
- The most recent version of OPNET includes a model for ATM, as well as an highly simplified model for cellular radio (in that it does not account for all the interference caused by voice and data in an actual cellular deployment, nor for the actual number of channels available for CDPD — in no way a match for the MOSS+GRANET combination).
- Open environment and compatibility with C – OPNET is a set of UNIX-based C programs, and hence it is compatible with C. In addition, OPNET has an open design environment in which user-developed C programs can be easily incorporated into an OPNET program.

OPNET is a dynamic, event-driven simulation package and as stated above particularly suited as a simulation tool for modeling protocols and evaluating the performance of large communication networks. Some of the features of OPNET are listed below:

- OPNET has a hierarchical, object-based structure – Programming is done hierarchically from the network, the node, and the process/link models. The module is object-based, which allow the extensive reuse of the same code in different simulations.
- OPNET allows for the graphical specification of models – The input of the network topology can be done using the graphical interface. The library models can be selected using the graphical interface. Some programs can be written from the state transition diagram using the graphical interface.
- OPNET has comprehensive data analysis tools – There are many complicated data analysis functions in this package and specific variables can be probed and selected as the performance measures. The results of data analysis can be displayed using a powerful, user friendly graphical display.

OPNET is very versatile and powerful package, indeed an excellent match to the analysis required of the wireline network with its myriad possibilities of mixing and matching technologies to meet the needs of disparate scenarios and jurisdictions. Simultaneously, its wireless capabilities are increasing, with new cellular and satellite models recently added.

I.3.1 Wireline Communications

All Government-provided scenarios will be analyzed, for the evaluatory designs identified in the Physical Architecture. The same wireline topology alternatives analyzed in Phase I, namely Ring, Star, and hybrid, will be considered again in Phase II, where appropriated (a backbone infrastructure is not likely to exist in the rural scenario), for all transportation mechanisms already studied, namely FDDI, and Ethernet, with the addition of ATM modeling.

I.3.2 Wireless + Wireline Simulation Integration

As mentioned above, GTEL's MOSS deals primarily with the lower layers of the CDPD stack (Physical and MAC layers), taking into account in its entirety the actual cellular environment under consideration, providing realistic over-the-air delay characterization. The upper layers of the stack were not analyzed in detail since they were expected to add only a small fraction to the overall CDPD delay.

In Phase II, we have combined GTEL's precise characterization of the radio channel with Loral's protocol stack simulation capabilities. For that purpose, Loral's OPNET simulation of the CDPD stack will be enhanced by substituting GTEL's radio channel characterization for the lower layers of the stack. We expect thus to answer to the concerns expressed by the Technical Review Team (TRT) referring to the overall performance of the CDPD channel.

I.4 Validation of the Modeling Tools

It is recognized that a primary problem in the development of any simulation is verification of the correctness of the simulation and the numerical results from the simulation. Whenever possible, the simulation results obtained using the models above will be compared with available field measurements. Otherwise, the following methods have been successfully used at GTE Laboratories to control the possibility of simulation error:

- Analytical Models – Where possible strong in-house analytical skills have been utilized to build analytical models. Typically, it is not possible to develop analytical models that capture as much detail as a good simulation, which is the reason for building the simulation. Nevertheless, analytical models provide data points for special cases and bounds for more general cases and have been used to check the operation of the simulations.
- Published Results – Results for certain designs and special cases are frequently published in the open literature. Such results have been used in the same way as internal modeling efforts to provide data points and bounds for verifying internally generated simulation results.

Industry and Professional Contacts – GTE Laboratories staff members have extensive contacts in the industry, through participation in industry standards activities and other industry meetings, working arrangements with cellular equipment manufacturers, and professional and academic relationships. Results from work in progress in other companies on performance evaluation have been and continues to be available through these channels when not available elsewhere. This input has frequently proven to be very useful in validating internal simulation results.

APPENDIX J CDPD FIELD TRIAL RESULTS

J.1 Introduction

This appendix presents a synopsis of the results of a technical trial where CDPD was used as the communication medium to transfer information between a fleet of vehicles and a fleet management dispatch center. The trial was performed during the first half of 1995 in GTE Mobilnet's San Francisco Bay Area Region. The trial involved GTE Mobilnet and GTE Laboratories in collaboration with Rockwell International who provided the software and hardware of their "FleetMaster" fleet management application. It also involved a commercial fleet customer (to remain confidential).

The trial activities included adapting the Rockwell FleetMaster hardware and application software (which was initially developed to operate over conventional SMR) to interface with CDPD modems and to operate smoothly over the CDPD network. (In the FleetMaster system, each vehicle carries a "NavCell" which contains a GPS receiver which determines vehicle location from GPS satellite transmissions. The CDPD network provides communication with the personal computer-based FleetMaster base station located in the Fleet operator's dispatch center.) The trial included a host of technical field tests and culminated in demonstrations of performance in customer fleet vehicles.

The remainder of this appendix will summarize the salient components of the trial and will focus on the CDPD application's end-to-end performance results demonstrated in the field. The exposition will essentially be limited by the need to protect proprietary and competition sensitive information pertaining to both the FleetMaster product and GTE's CDPD network infrastructure. Business related results are also not included.

J.2 Trial Objectives

The first broad objective of the field trial was to investigate and assess the technical feasibility and viability of CDPD service for local commercial vehicle operations with a real customer. The second broad objective was to gather data on message traffic and billing in order to assess service structures and pricing for local truck dispatch operations.

The objectives of the trial translated into the following field testing tasks:

- Verify satisfactory operation of the FleetMaster application and its interface to the CDPD network.
- Test operation with different transport protocols (TCP and UDP).
- Verify satisfactory CDPD coverage throughout the area served by the commercial fleet customer.
- Verify mobile operation, particularly prompt recovery from any radio outages (e.g., due to tunnels or mountains), and smooth, rapid sector hand-offs.
- Perform side-by-side comparisons of multiple CDPD modems, particularly regarding speed and reliability of hand-offs.
- Test CDPD system loading limits.
- Obtain billing records of on-the-air operation to allow customer-specific cost prediction.
- Obtain extensive log files for detailed post-field-trial investigations.

J.3 Trial Participants

A trial of a new infrastructure technology with a new, emerging customer application is a major effort that requires a significant amount of coordination, as well as an engineering and business team with specialized and synergistic capabilities. This is reflected in Table J.3-1.

Table J.3-1 Participating Organizations and their Responsibilities

Participant	Responsibility
GTE Labs	• Trial Plan Preparation • Test Plan Development • Lab Integration, Setup and Testing • CDPD protocol analysis support • Field Testing (Bay Area) • CDPD Field Performance Evaluation
GTE Mobilnet	• CDPD Operation and Network Support • Lab and CDPD analysis support • Provisioning & Billing System Support • Customer Satisfaction Assessment
Rockwell	• Dispatch Center Hardware/Software • CDPD Application Software • Mobil Unit Hardware/Software • System Installation, Integration & Testing • Test Plan Development Support • Customer Satisfaction Assessment
Customer	• Performance Evaluation • Truck Fleet Test Platforms • Host for Control Center

J.4 FleetMaster System and Trial Configuration

The configuration and connectivity used in the trial is shown in Figure J.4-1. In the FleetMaster system, each vehicle carries a NavCell which contains the GPS receiver, processing, and a communication interface (RS-232). When configured for SMR operation, the NavCell contains a modem board which interfaces to the audio input of the SMR radio. When configured for CDPD operation, a CDPD modem (transceiver) is connected to the communication interface to provide connectivity, through the CDPD network, to the fleet operator's dispatch center as indicated in Figure J.4-1. CDPD modems (actually modem/radio transceivers) are provided by third party vendors. Modems from Cincinnati Microwave Inc. (CMI) and PCSI were used in the trial. More extensive testing was performed with CMI's DART-100 modem due to software development considerations in the FleetMaster system during the trial period.

The personal computer-based FleetMaster base station located in the dispatch center contains geographical data. This interface consists primarily of a map display window on which icons show the current locations of vehicles being tracked. In addition, there is a system message display window and other interactive interface tools that enable the system operator to control the display parameters, vehicle configuration, communication parameters, polling/reporting status, and other aspects of the system.

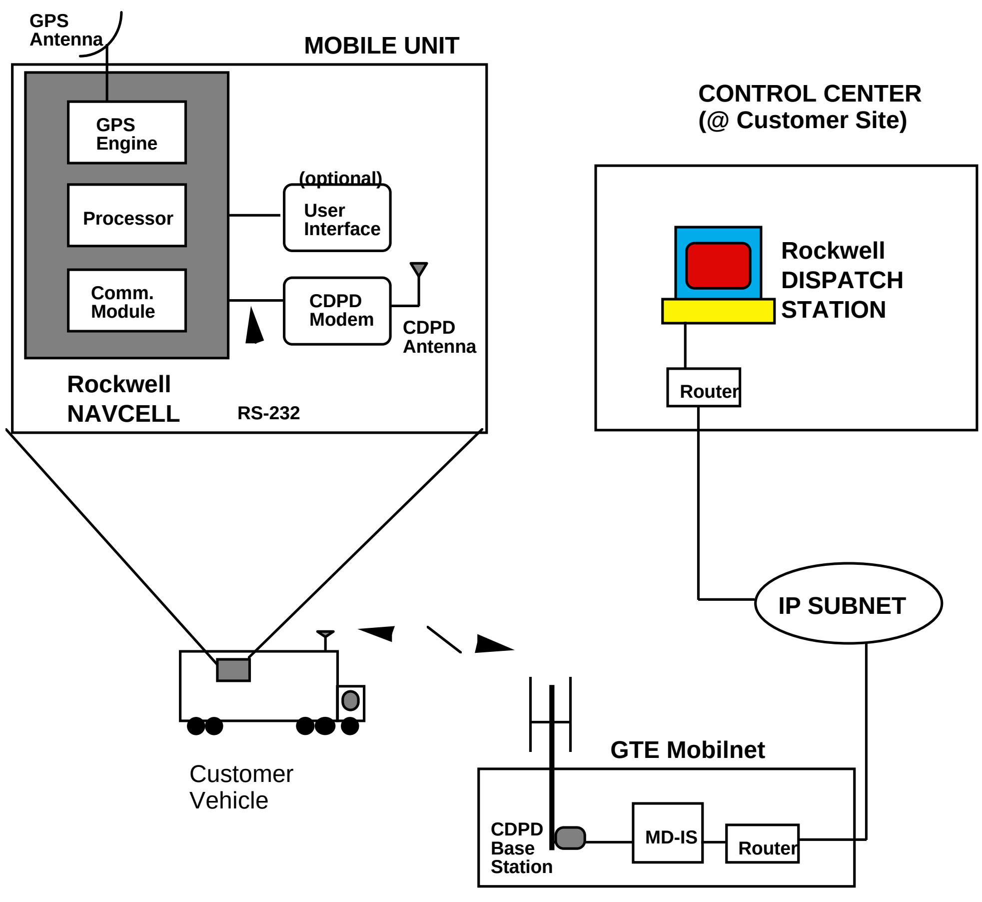

Figure J.4-1 CVO-CDPD Field Trial Configuration

J.5 Sample Field Results

J.5.1 Signal Strength and Waiting Time Measurements

Runs were performed as early as January 24-27, 1995. In CDPD terminology, the Mobile End System (MES) consisted of the NavCell connected to the CDPD modem. The CDPD modem used was CMI's MC-DART 100 and the protocol used during those runs was TCP. The CDPD deployment at the time was in many but not all voice cells in the San Francisco Bay area. (Roughly half the cells for voice covering the entire cellular region, extending from Napa to Santa Barbara, were deployed). The deployed cells had one CDPD dedicated channel per sector. A rental vehicle was used to travel some extended routes in the Bay Area while a ThinkPad laptop computer equipped with an internal Ubiquity 1000 CDPD modem measured and recorded signal strength in the vehicle. Although the signals received by the MC-DART with an antenna external to the vehicle and the Ubiquity modem with an attached antenna are not instantaneously correlated, this setup provided very useful macroscopic information on the propagation conditions encountered in the field. This is particularly true in light of the incomplete CDPD deployment at the time.

To facilitate the analysis of the test results, complete logs were kept of the experiment. These included the logs of the TCP/IP software (from Distinct) residing at the dispatch center (also called the Fixed End System or FES in CDPD language), which kept track of all IP packets originating and destined to the FES, and the ThinkPad logs which included information on signal strength and selected channel in a given cell. Besides these logs, the FleetMaster application logs (also at the FES) registered all transactions, including all retrials. The FleetMaster system was configured to poll the vehicle regularly. (As will be discussed later, during normal fleet operation vehicle reporting without polling is the more efficient approach used.)

Figure J.5-1 shows the signal variation measured during the longest run around the Bay Area with the IBM ThinkPad with built-in Ubiquity 1000 CDPD modem programmed to log the received signal strength every 10 s. Besides the usual short fades encountered in the mobile environment, a few long "fades" were also experienced. Those were easily identified with some sheltered canyon situations, a long tunnel, and the lower deck of the Bay Bridge, were CDPD coverage had not yet extended.

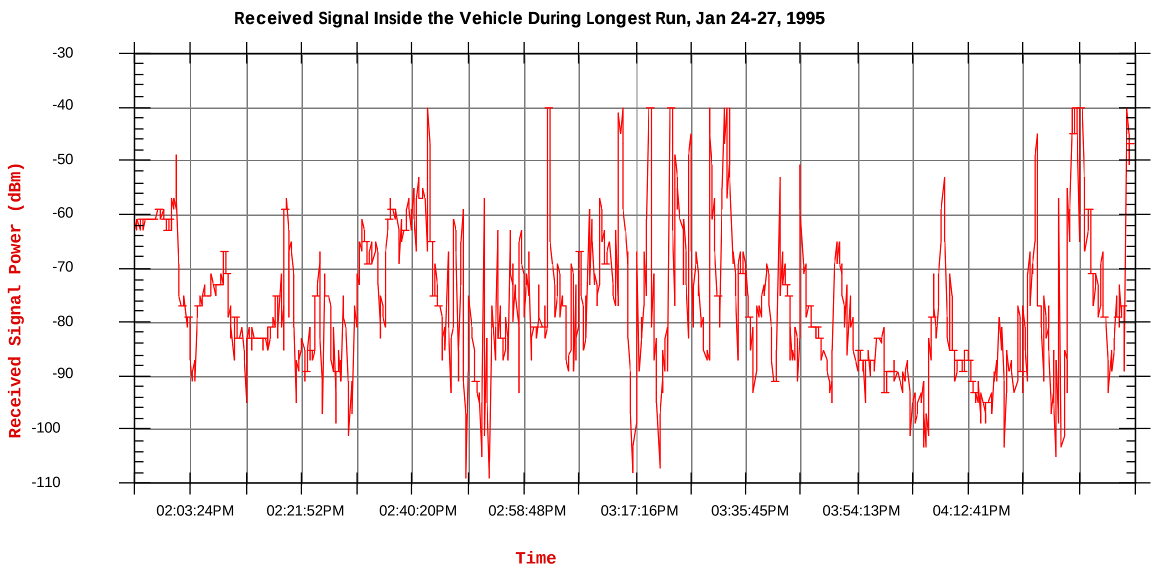

Figure J.5-1 Received CDPD Signal Strength Inside a Vehicle During a Run in Jan. 1995

The wait associated with the polling transactions, defined as the time between the polling query and the reception of the answer at the F-ES, measured from the Distinct log files, is shown in Figure J.5-2. (Instances where polling was not successful due to lack of coverage, as in a tunnel or sheltered canyon are not represented in the plot.) Tests were performed during different hours of the day, and many were performed during the afternoon/evening rush hours. Two way end-to-end delays stayed generally below 1 s, and showed no particular dependence on the time of the day. Figure J.5-2 and J.5-3 show the probability density function (pdf) and the cumulative distribution function (cdf) of the waiting time, respectively. The average wait for an answer from the NavCell was 0.812 s. In practice, this limits the polling rate with TCP to once every few seconds. (Typically in a commercial application a much less frequent update rate is used.)

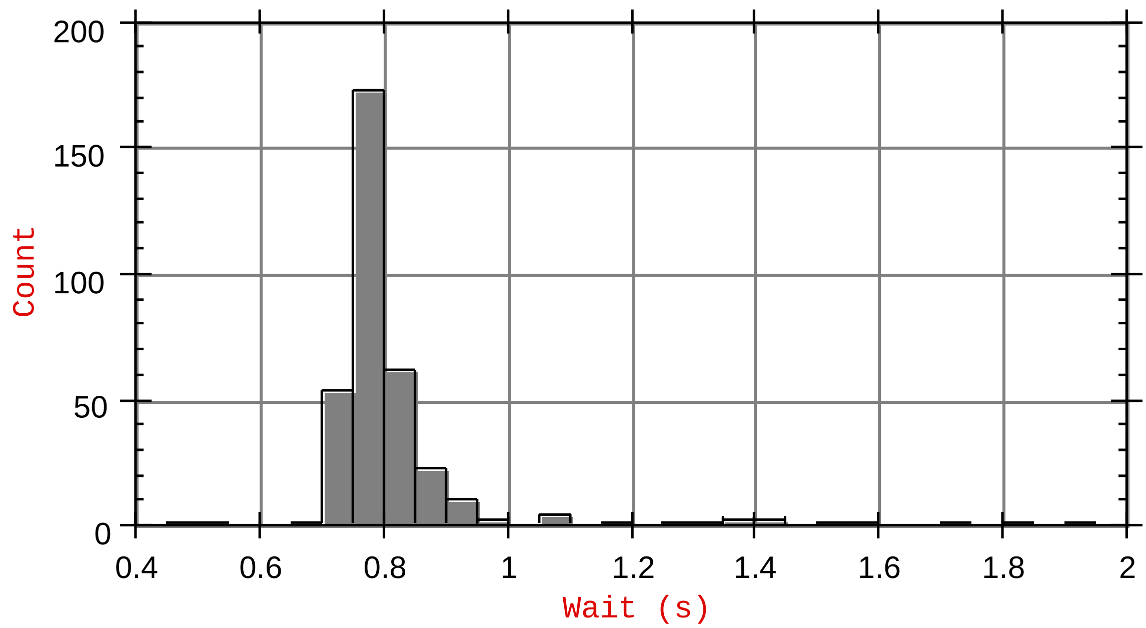

Figure J.5-2 PDF of the Polling Waiting Time

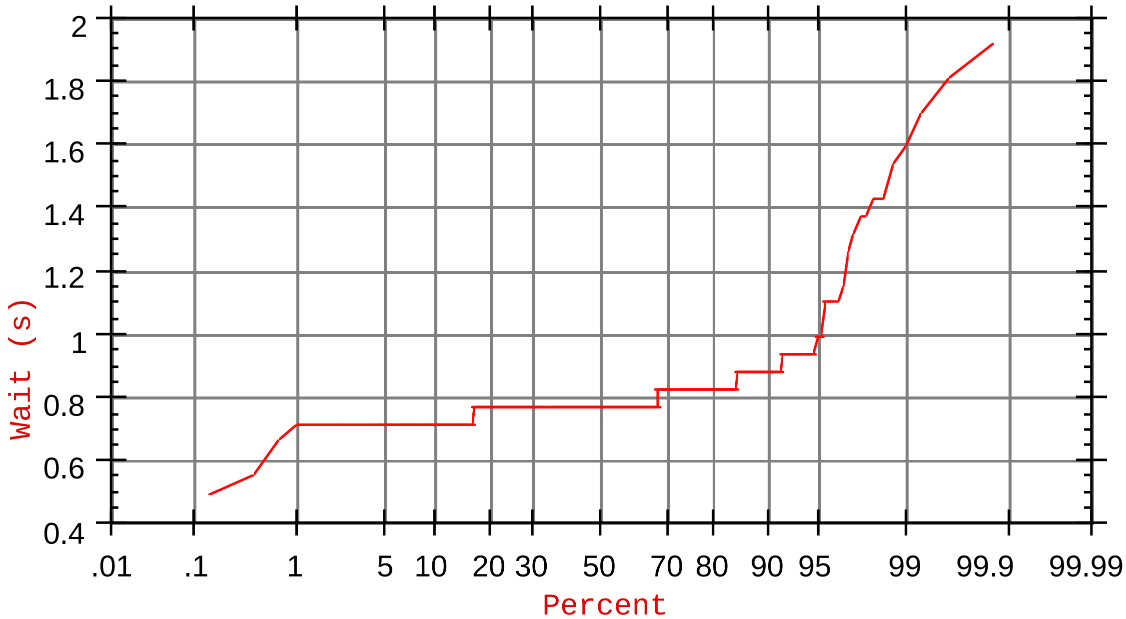

Figure J.5-3 CDF of the Polling Waiting Time

J.5.2 TCP versus UDP

The adaptation of FleetMaster to CDPD, involved the typical challenges of upgrading from a legacy communication technique to a modern, information age one. CDPD is a TCP/IP protocol suite-based system. TCP is responsible for maintaining reliable sessions between the mobile (MES) and the fixed dispatch center (i.e., the FES). In a traditional radio system, no such intelligence exists. Hence the application layer itself is responsible for maintaining the integrity of the end-to-end link. Correspondingly, the application, when requested (as an option) performs the acknowledgments. Although the difference between having the application and transport layers perform this maintenance task seems insignificant at first blush, it is anything but that when successful interfacing of the application software to the protocol stack is the task at hand. Significant application software adaptation is required to avoid anomalous operation when outages are encountered-- as they inevitably do in a dynamic wireless environment.

A fleet dispatch application is one wherein repeated transmissions from the vehicle take place over time as the vehicle progresses along its route. In many cases, an acknowledgment is not required if the transmission medium is sufficiently reliable and the dispatcher can tolerate the occasional loss of a position report.

Because of the original design of the FleetMaster application and the observed overall reliability of the CDPD medium it was decided in the middle of the trial to switch from TCP (guaranteed delivery) to UDP (not guaranteed). Since the application is capable of acknowledgment when requested to do so, extremely high reliability could still be maintained with UDP when desired.

In addition to the simplification in programming the application interfaces, a cost advantage is realized for the customer. UDP has a small billable header of 8 bytes. TCP on the other hand, has a header of 20 bytes; moreover, all routine transport layer acknowledgments are also billed per byte. Thus, the guaranteed delivery of TCP comes at a price, which can be avoided in the fleet dispatch application over CDPD. It should be noted that TCP header compression, which is implemented automatically for transactions containing multiple packets, is not useful here, nor in most ITS mobile applications, because the transactions are typically short (few tens of bytes), and fit well within a single CDPD packet.

J.5.3 CDPD System Loading Limits

During the March 27 - 30, 1995 period a simple but telling test of the CDPD system's loading limits was performed. Operating two NavCell/MC-DART mobile units within the same sector reporting at the intentionally exaggerated rate of once per second did not cause any appreciable network delays. (UDP was the protocol used at that point.) Adding other significant background users in the same sector started causing delays and intermittent operation of the application. The capacity demonstrated successfully, however, far exceeded the requirements of the application or network loading in the foreseeable future. It is equivalent to the simultaneous operation of 600 NavCell/CDPD-equipped vehicles in the same cell sector if we assume a more representative five minute reporting interval.

J.5.4 Application Inter-Arrival Times with UDP

During tests conducted on March 29-30, 1995, position reports were transmitted from the mobiles either autonomously at approximately fixed intervals or in response to polls sent from the dispatch center at approximately fixed intervals. (The software timers in both ends of the application depended on previous events and did not follow precise repetition intervals.) If the vehicle were in a "hole" in coverage, or if the application were in the process of recovering from an outage, position reports would not be received at the expected intervals. Thus, by examining the intervals separating the arrivals of position reports at the dispatch center, insight was into both the coverage of the CDPD system and operation of the FleetMaster application when using UDP.

On March 29 a mobile unit was set to "broadcast" – that is, report to the dispatch station – at 15 second intervals without acknowledgments from the dispatch station. Figure J.5-4 indicates that the inter-arrival times were tightly clustered around a value slightly higher than the preset value. In addition, a number of position reports arrived at very small intervals. The FleetMaster log reveals that on a number of occasions a brief outage was followed by the arrival of several position reports in rapid succession. Only nine out of 312 intervals exceed one minute, indicating a success rate of 97%.

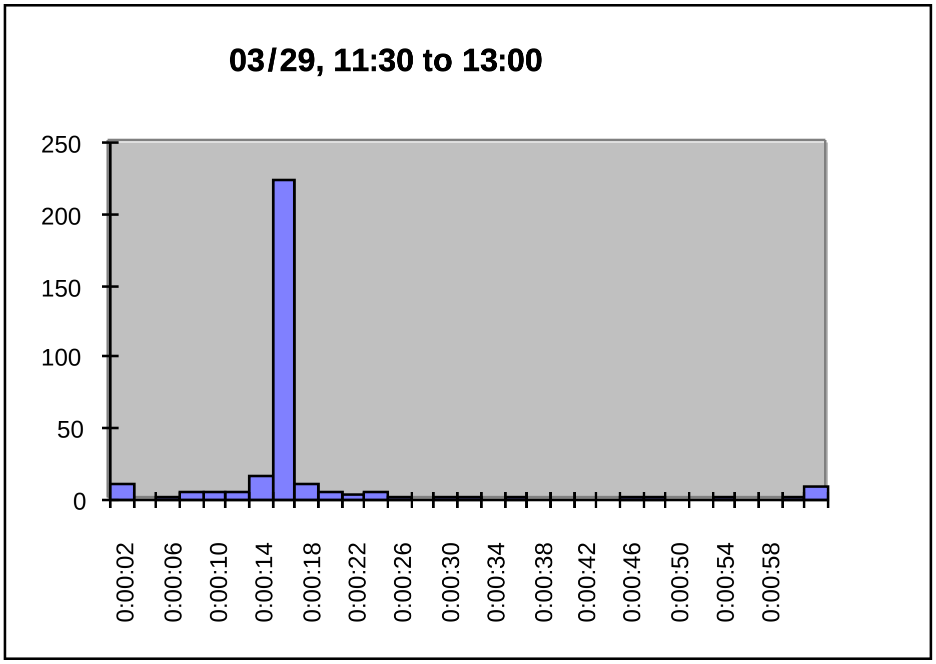

Figure J.5-4 Histogram of Inter-Arrival Times Between Position Reports in FleetMaster Log (reporting at roughly 15 s intervals without ACK)

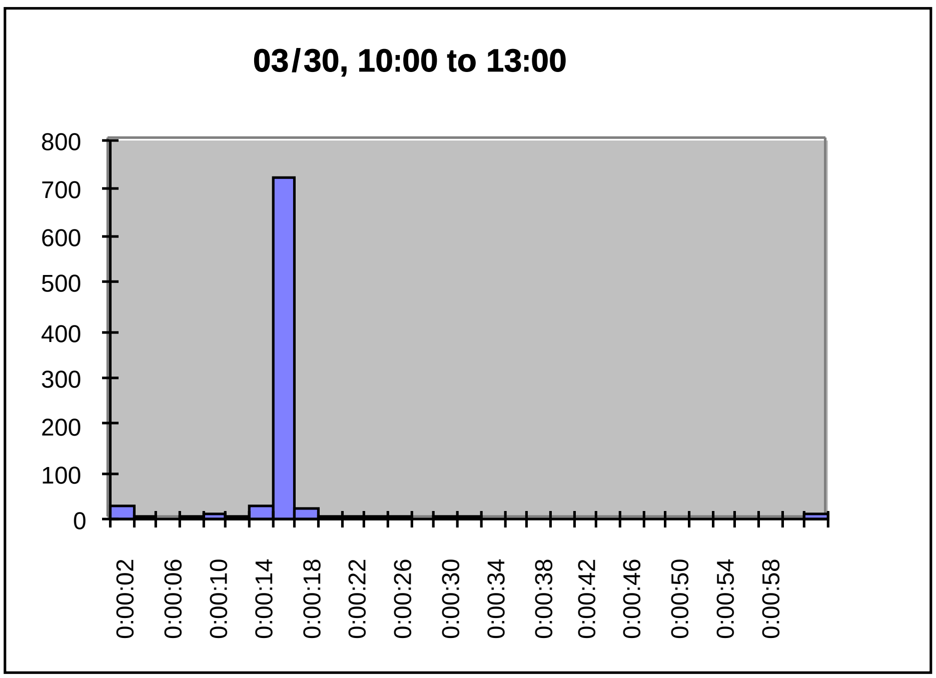

Figure J.5-5 Histogram of Inter-Arrival Times Between Position Reports in FleetMaster Log (reporting at roughly 15 s intervals without ACK)

On March 30 another mobile was set to “broadcast” position reports at 15 second intervals without acknowledgments from the dispatch station. Only twelve out of 861 intervals exceed one minute, indicating a success rate of 99%. This is depicted in the histogram of Figure J.5-5.

A second unit was set to “broadcast” position reports at 30 second intervals but with acknowledgments from the dispatch station. Only twenty out of 343 intervals exceed one minute, indicating a success rate of 94%.

Finally, a third unit on the same day was configured to resemble a more realistic operational environment over a very wide geographic area during a three hour run. The mobile was polled by the dispatch station at 5 minute intervals. If no response was received a second pole was sent automatically after 30 seconds. Figure J.5-6 indicates only two instances out of thirty where the interval between position reports differed significantly from the five minute value. This indicated a success rate of 93%.

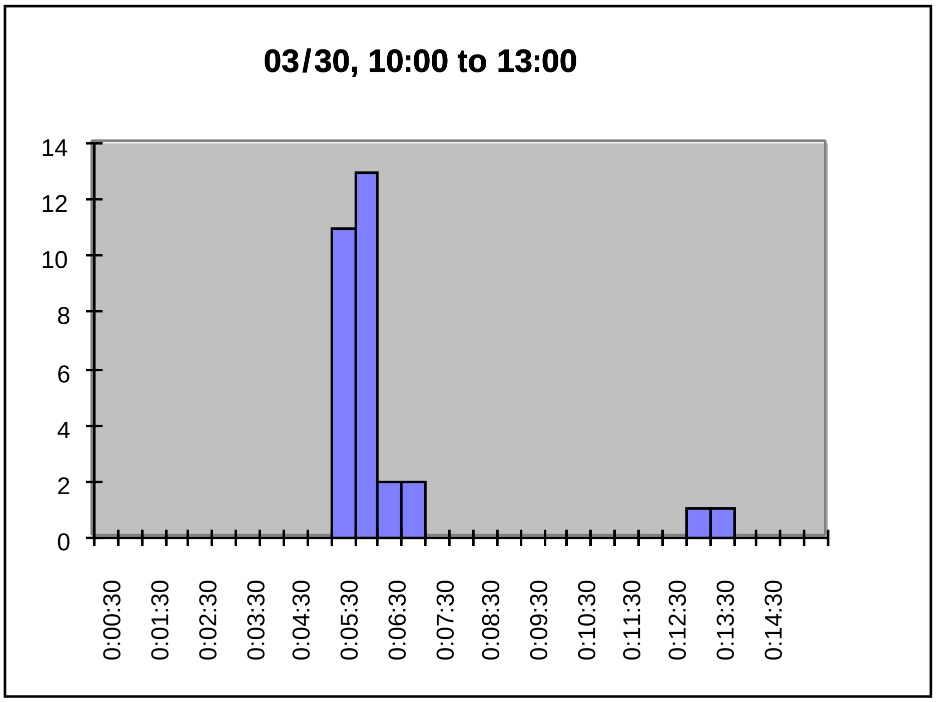

Figure J.5-6 Histogram of Inter-Arrival Times Between Position Reports in FleetMaster Log (Polled at roughly 5 minute intervals with re-poll at 30 seconds.)

The primary conclusion to be drawn from this analysis of inter-arrival times is that coverage in the area served by the fleet customer was generally good, with success rates ranging from 93% to 99%. This includes the severe environment of downtown San Francisco. There are some localized areas where there are holes in CDPD coverage. These should not impact customer operations significantly, and would be eliminated as the CDPD deployment continues.

An additional conclusion that may be drawn from the inter-arrival time data is that operation of the application using the UDP protocol was smooth. In general it was observed that the application recovered quickly from any outages which occurred due to holes in coverage. Finally, network operation seemed to be completely transparent to the application in the sense that no significant delays are incurred in handling the CDPD traffic. As mentioned earlier, there was no perceptible variation in the performance as a function of the time of day or the voice activity on the rest of the cellular network.

J.6 Operation in Customer's Vehicles and Billing System Validation Tests

A billing validation test was performed using the three customer vehicles equipped with NavCells . The vehicles conducted an approximately ten hour operational run in the Bay Area and the FleetMaster application logs were compared with information obtained from the billing system of GTE Mobilnet.

The NavCells of the three vehicles were configured by the FleetMaster dispatch computer to transmit at three different intervals (1) thirty seconds, (2) one minute, and (3) five minutes. The three vehicles had different routes. Vehicle #1 traveled from Oakland to San Francisco, spent most of the day traveling in San Francisco, and then returned to Oakland. Vehicle #2 spent most of the day traveling in the areas south of San Francisco, traveling from Oakland to San Francisco, to Burlingame, San Mateo, Redwood city, San Carlos, Belmont, Foster city, Hayward, San Leandro, and then back to Oakland. Vehicle # 3 traveled primarily in the East Bay, from Oakland to Concord, Walnut Creek, Lafayette, to San Francisco and then back to Oakland.

For the duration of this experiment, the Customer's FleetMaster dispatch computer recorded the transactions from the three vehicles at the specific rates (for example, thirty second intervals). The recorded transactions included the following information: (1) time, (2) status, and (3) location.

The records of the FleetMaster transactions were inspected and the total number of bytes was calculated for each vehicle. The summary of the results is depicted in Table J.6-1, which also presents the reported transaction bytes from the Mobilnet billing system.

Table J.6-1. Comparison of Application Log and Billing Records

Vehicle ID	Interval Between Transactions	Total No. of Bytes* from Customer's FleetMaster Log	Total No. of Billable Bytes from Mobilnet Billing System	Deviation Between the Billing Record and Customer FleetMaster Log
Vehicle #1	30 Sec.	82946	83376	0.5 %
Vehicle #2	1 Min.	44402	44294	0.2 %
Vehicle #3	5 Min.	6538	6550	0.18 %

* Application (vehicle report) data payload plus the 8-byte UDP header per transaction (a few non-standard size transactions at power-ups are also accounted for)

J.7 Summary of Conclusions

The trial demonstrated that the CDPD network is technically very well suited to the needs of fleet management systems. Specifically, it was found that:

- The CDPD system's loading limits well exceed the requirements of the application or network loading in the foreseeable future.
- End-to-end delay experienced in the CDPD network is on the order of a second and has a positive impact on operation of the application.
- Coverage in the area served by the commercial fleet customer was generally good, with transmission success rates ranging from 93% to 99%. This included the severe environment of downtown San Francisco. (Only a fraction of the base stations in the entire cellular territory of GTE Mobilnet were equipped with CDPD at the time; the service roll-out has since expanded.)
- Billing records accurately represented actual network traffic.
- CDPD modems from two manufacturers had different characteristics including different speed of hand-off between cells or channels.
- The UDP protocol is more suitable for operation with the FleetMaster application than TCP. In addition, UDP is more cost-efficient for the customer due to its lower packet overhead and the elimination of transport layer ACK's.
- A CDPD approach is a viable, cost-effective solution for fleet management operations.