Communication Technologies for AHS*

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Abstract

Candidate communication technologies for AHS applications are presented. In particular, we discuss the design issues and the performance evaluation of packet radio technologies. The main focus is on the analysis and interaction between the Physical and the Link-access layers of a packet radio system that can accommodate communication between vehicles and infrastructure as well as between vehicles. We discuss the information flow requirements of ATMIS and AVCS services and we present preliminary results from the performance evaluation of two packet radio technologies (Reservation-ALOHA and CDMA).

1. Introduction

AHS (Automated Highway Systems) is a joint effort of public, private and academic sectors to develop and deploy solutions that can alleviate the existing transportation problems. AHS will incorporate communication, control, and transportation technologies in order to improve the traffic flow and safety in existing freeways and surface streets. Efficient use of the existing transportation facilities and energy resources promises to reduce the current levels of congestion, thus improving the air quality and protecting the environment [1].

The objectives of our study are to identify, analyze and evaluate packet radio communication architectures for AHS. Our efforts have focused on the analysis and interaction between the Physical and the Link-access layers of a packet radio system that can accomodate real-time, interactive communication between vehicles, as well as between vehicles and infrastructure.

This study interfaces strongly, and complements, other related research efforts in the general area of consideration. In particular, the system architecture and design draws on the conclusions of the AHS study [2] in order to conform with its evolving specifications. It also relies heavily on the source-characterization findings of other ongoing research projects for the purpose of refining the details in the data traffic characterization.

In section 2, we discuss the functional requirements of several AHS applications and services. Section 3 presents the data requirements for two AHS applications; ATMIS (Advanced Traffic Management and Information Systems) and AVCS (Advanced Vehicle Control Systems). The suitability of several candidate communication technologies and a general analytical tool for the design and evaluation of a packet radio communication system for AHS applications are presented in sections 4 and 5, respectively. The performance evaluation of two packet radio technologies (Reservation-ALOHA and CDMA) is presented in section 6. Finally, in section 7, we discuss the conclusions we have reached thus far for the applicability of the two technologies.

2. AHS Functional Requirements

It is expected that various types of applications/services will be provided to meet the goals of AHS and satisfy customer needs. A partial list of AHS user services that are envisioned is as follows:

- Traveler Information – such as traveler advisory, traveler information services (value-added), trip planning, position location systems, navigation, route guidance, weather information, visitor attractions, restaurants, events, hotels, gas.

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	Vehicle to BS	BS to Vehicle	Vehicle-to-Vehicle	
			Intra-platoon	Inter-platoon
ATMIS	Info requests Traffic probe (short messages)	Traveler info & advisory (long messages)	—	—
AVCS	Platoon status information Requests for lane changes (short messages)	Target velocity & acceleration Handling of lane changes (short messages)	Lane keeping maneuvers Lane changing maneuvers (short messages)	Lane changing maneuvers (short messages)

Table 1: ATMIS/AVCS Information Flow Requirements

- Traffic Management – such as incident detection and management, demand management, traffic network monitoring, traffic control, parking management, workzone management, and automatic toll collection.

- Vehicle Control Systems – such as adaptive cruise control, collision warning, collision avoidance (automatic braking & lane departure warning systems), longitudinal (speed and spacing) and lateral control (steering).

- Freight and Fleet Management – such as intermodal transport planning, route planning and scheduling, hazardous material monitoring and tracking, vehicle and cargo monitoring, law enforcement and regulatory support.

- Public Transportation and Emergency Vehicle Management – such as planning and scheduling systems, signal pre-emption traffic control, automatic payment, dynamic ride sharing, prediction of arrivals, and emergency services systems management.

- Additional Services – such as traveler safety and security, MAYDAY transmissions, and hazard warning.

Naturally, it would be desirable to have a single communications infrastructure to support all the applications envisioned within AHS. However, it is conceivable that more than one communications interface will be in a vehicle because of the differing requirements of different applications. Each of the envisioned applications has its detailed requirements such as the volume of data to be communicated, the size of the communication zone, the quality of the communication in terms of maximum tolerable bit error rate, the priority of the communication, the need for one-way or two-way voice or data communication, etc. Clearly, a wide range of requirements is possible.

3. ATMIS/AVCS Information Flow Requirements

The integration of ATMIS and AVCS services promises to improve the traffic flow in existing freeways and surface streets and at the same time increase substantially the transportation safety and capacity of the freeways [3]. The two applications have been thoroughly examined in [4] in order to extract the communication needs and the data requirements of an integrated ATMIS/AVCS system. Knowledge of data requirements is necessary for the determination of the communication requirements of the integrated system and also, for the estimation of spectrum needs and evaluation of the applicability of candidate communication technologies.

The information flow requirements associated with the various communication needs are summarized in Table 1 [4]. We notice that uplink (vehicle to base station) and vehicle-to-vehicle communications require the exchange of short messages (64 - 100 bits) for both ATMIS and AVCS transactions, since they contain only control information (velocity and acceleration), or simple requests for information [5], [6]. The message size for the downlink (base station to vehicle) however, depends on the application. AVCS services require transmission of short messages, whereas ATMIS services such as traveler advisory and information (including the transmission of digitized maps) require the transmission of long messages which can be broken up into several packets, each containing, say, 512 bits [7]. The study of the data requirements for the integrated system has concluded that the AVCS communication needs require periodic, high data rate, real-time data traffic, whereas the ATMIS data traffic is non-periodic, low data rate, and non-real-time.

Technologies	ATMIS	Vehicle/Hwy Automation	Public Transport	Fleet Management	Truck Monitoring	Rural Systems
Subcarrier FM RDS, SAP, SCA	Some Voice, Data	No	Some	Niche	No	Some
HAR 530/1610 kHz	Some V	No	No	No	No	Some
Leaky cable	Some V	No	No	No	No	Some
LEO Satellites GEO	Yes V, D Cost	No	Yes V, D	Yes	Wide area	Yes V, D
Beacons IR, Microwave	Yes D	Some (Veh/Veh)	Some D	Some	Yes D	Some
2-way wide area radio	Yes V, D	Some	Yes V, D	Some	Yes V, D	Yes V, D
Cellular Voice,data	Yes? V, D	Some	Yes V, D	Some	Yes V, D	Yes V, D
Inductive loops	Very few D	Maybe	No	No	No rail Y	Very few
HF	?	No	No	No	No	?
PCS Microcellular	Yes? V, D	Maybe	Yes V, D	No	Yes V, D	No
Meteor burst	No	No	No	?	No	No

Table 2: Applicability of candidate technologies to different types of services

4. Technology Availability

Several technologies have been suggested as candidates in order to provide communications for AHS applications. They include subcarrier FM TV, SAP signals, Highway Advisory Radio (HAR) at 530 kHz and 1610 kHz, leaky cable, satellites (LEO, GEO), beacons (IR and microwave), 2-way wide area radio, cellular systems, inductive loops, HF, Personal Communication Services (PCS), microcellular, and even meteor burst. Some technologies are more suitable for certain services than others. Table 2 shows the applicability of communication technologies to different types of services.

Communication requirements are also dependent on the overall AHS system architecture. For example, a centralized architecture requires more communications than a decentralized or distributed one. The task of setting AHS communications requirements and proposing standards is particularly difficult because of the great variety of AHS systems under consideration, and because these systems are expected to evolve with time. The system architecture has to be defined before specifications or standards can be considered meaningfully. The specification of the communication protocols depends partly on how spatial and temporal aspects of traffic networks are implemented, and how intelligence is distributed between the infrastructure and the vehicles.

5. Packet Radio Architectures

Table 2 shows that there is no single technology that can accomodate the communication needs of an integrated ATMIS/AVCS system. A short-range, packetized, either random- or reservation-access based radio system is however, a feasible, viable and cost-effective solution for addressing the currently perceived (and rapidly evolving) requirements for a vehicle-to-infrastructure and vehicle-to-vehicle communication system for AHS [7]. Our efforts have focused on the identification, analysis and evaluation of such packet radio communication architectures. In particular, we have studied the trade-offs for designing the Physical and the Link-Access layers of a packet radio system that can accomodate real-time, interactive communication between vehicles, as well as between vehicles and infrastructure.

In order to study and quantify the interaction between the Physical and the Link-Access layers of a packet radio system that can accomodate the communication needs of the integrated ATMIS/AVCS services, we have devised a generic conceptual model (Figure 1). The model includes two modules for the performance evaluation of the two layers and identifies the effects of design options, vehicular traffic, physical environment, information flow and communication system requirements on the evaluation procedure.

In the Protocol Layer Design and Evaluation Module,

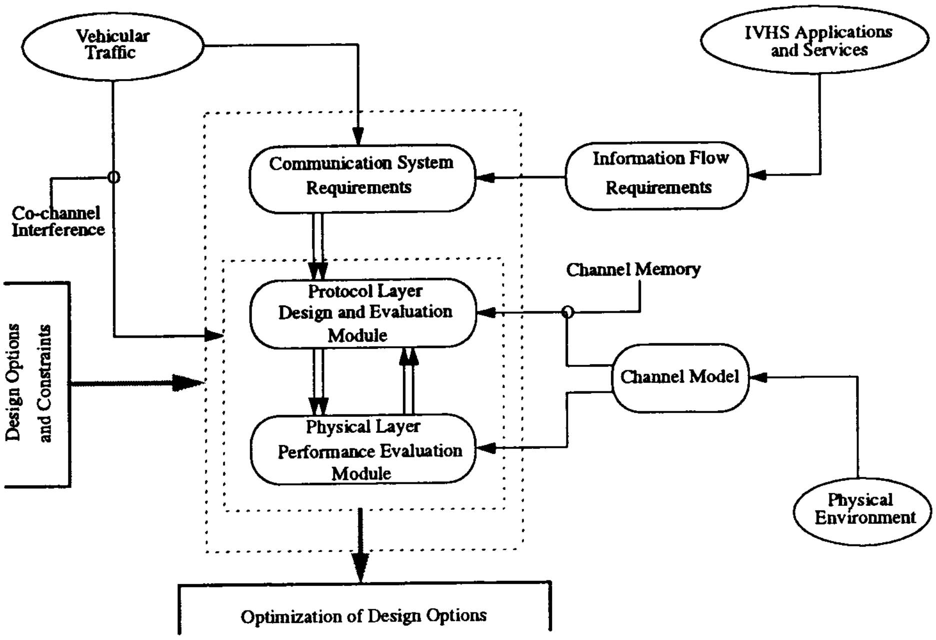

Figure 1: Integrated-Layer Model

the suitability of existing protocols for AHS communications is evaluated. The inputs to this module include the communication system requirements, the memory of the radio channel, and the physical layer parameters, such as the bit error rate and the packet error rate. The measures for evaluation of a protocol's performance are the throughput-delay for the vehicle to base station link (non-periodic data traffic), and the deadline failure probability for the vehicle-to-vehicle link (periodic data traffic).

The Physical Layer Performance Evaluation Module is a general analytical tool that handles a wide range of options. The inputs to this module are the channel characteristics (propagation path loss, shadowing, multipath fading, duration of fades, delay spread), the users' spatial distribution (vehicular traffic), and the performance measures generated in the Protocol Layer Design and Evaluation Module. The performance measures of interest are the bit error probability, the packet error probability, the capture probability, and the outage probability. This module can be used for the analysis of both spread spectrum and narrowband systems in combination with various coherent and non-coherent modulation schemes. The coding, synchronization, diversity (micro, macro) and power control issues are also taken into account for the evaluation of the performance measures.

This model reveals the strong interaction between the Physical and the Link-Access layers of a packet radio system. Furthermore, the external inputs affect both layers, thus making the separate evaluation of some performance measures in each layer a difficult task. Therefore, in order to optimize the overall system, we must jointly optimize the two layers, rather than design, analyze, and optimize each layer independently from the other.

6. Performance Evaluation

The performance of Reservation-ALOHA and CDMA is evaluated for a lineal microcellular highway system where the users are assumed to be uniformly distributed in the cell. The cell size is approximately 1 km and the base station is located at the center of the cell. The antenna height of the base station is low (e.g., lamp post height) and the transmitting power is typically a few tens of mW. Because of the short propagation path, there exists a Line-Of-Sight (LOS) path between the base station and the users (sometimes the LOS path may be blocked by trucks, buses, etc.) giving rise to Rician fading with log-normal shadowing. The average rms delay for these systems is very small (in the order of nsec) [7]. The typical propagation loss model in microcells is described by the law [8]

$$L_p(r) = C_p\, r^{-a}\, (1 + r/g)^{-b}$$

where C_p is a constant, a is the basic propagation loss exponent, and b accounts for the additional propagation loss for distances beyond the Fresnel break point g. In the following subsections we present the results from the performance evaluation of Reservation-ALOHA and CDMA (Code Division Multiple Access).

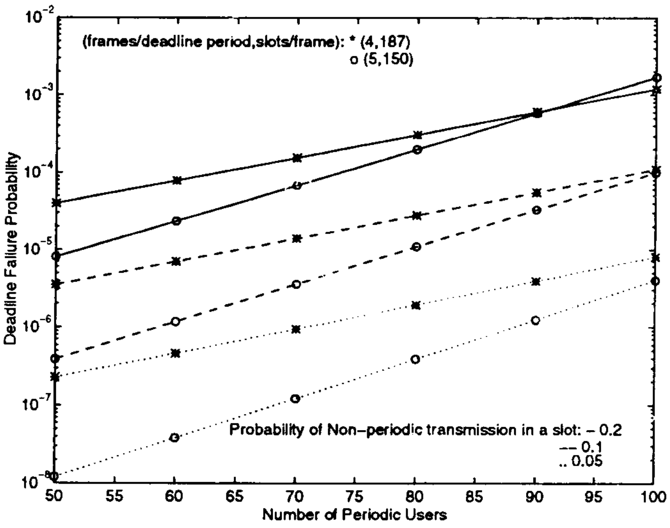

Figure 2: Deadline Failure Probability versus number of periodic users

6.1 Reservation-ALOHA

Reservation-ALOHA combines the simplicity of a random access scheme in the initialization stage and the good utilization of a reservation scheme in the steady state. Thus, it can accommodate the communication needs of an integrated system where the major percentage of the average data traffic consists of periodic vehicle-to-vehicle data traffic. The most important performance measure for this scheme is the Deadline Failure Probability (DFP) (i.e., the probability that the delay of a real-time packet is longer than the deadline period).

The performance of a Reservation-ALOHA system has been evaluated in [9] for a worst case scenario (none of the users has a slot and all of them are competing for one), and also for the steady state (all users have reserved a slot). Figure 5 presents the results for the DFP in the steady state. Although a large number of slots per frame is needed in order to ensure that the DFP is acceptable, this number is in the order of 1.5 to 2 times the total number of users in the locality of a vehicle. Furthermore, the simulation results have indicated that it is preferable to have more frames (each frame having a fewer number of slots) in a deadline period than a single frame with a fixed number of slots. The analysis has also shown that the presence of non-periodic data traffic can signficantly decrease the DFP. Thererefore, it is better to separate the two types of data traffic by reserving a number of slots in each frame for the non-periodic users.

6.2 CDMA

A new analytical model for the uplink and downlink performance evaluation of a multi-cell DS/CDMA microcellular system for both Rician and Nakagami fading channel models with shadowing has been presented in [4]. The BER, the outage probability, and the Packet Success Rate (PSR) (in slow and fast fading channels) for both BPSK and DPSK are evaluated using the Improved Gaussian Approximation (IGA) [10] and the Standard Gaussian Approximation (SGA). This model accounts for the users' spatial distribution, the chip waveform, the power control, and the effects of macro-selection diversity on the reduction of Multiple-Access Interference (MAI) from other cells.

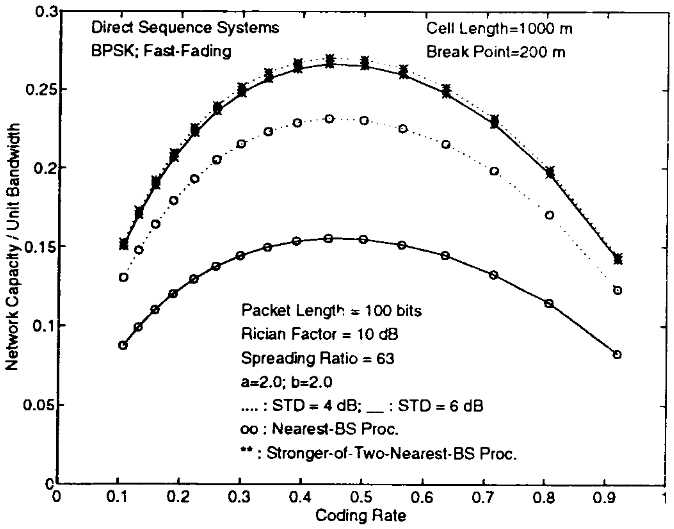

Figure 3: Normalized network capacity C_B versus coding rate for DS/CDMA systems with STD equal to 4 and 6 dB

The normalized network capacity for several channel and signal design options is shown in Figures 3 – 5. The figures show the significant effect of the Rician factor and the propagation loss exponents on the network capacity. We can also conclude that the optimal coding rate is insensitive to the spreading ratio, the standard deviation (STD) of the shadowing, and the propagation loss exponents. It depends however, on the fading rate (slow or fast), the modulation scheme, and the Rician factor (the larger the Rician factor, the higher the optimal coding rate).

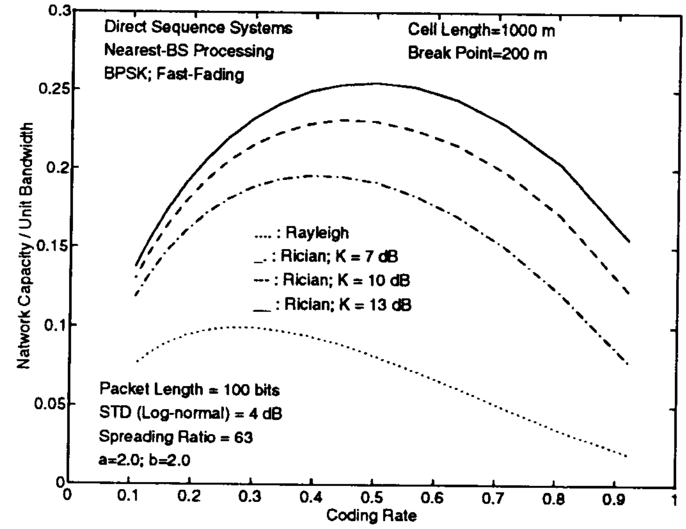

Figure 4: Normalized network capacity C_B versus coding rate for DS/CDMA systems for several values of the Rician factor in fast fading channels

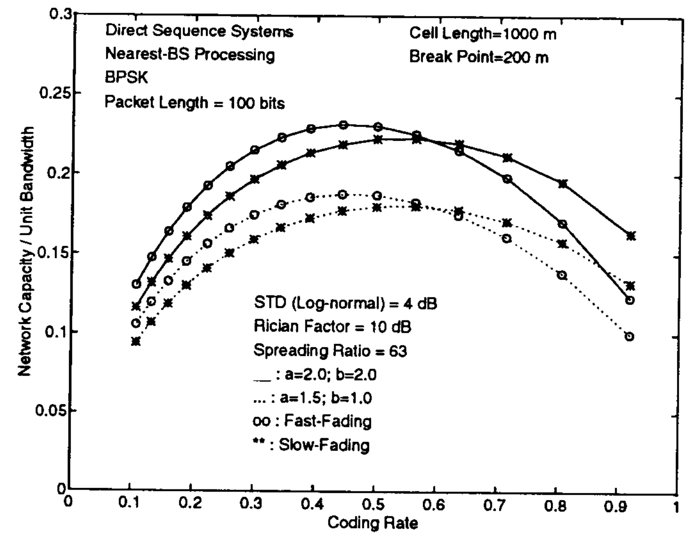

Figure 5: Normalized network capacity C_B versus coding rate for DS/CDMA systems for propagation loss exponents equal to (2,2) and (1.5,1.0) in fast and slow fading channels

7. Conclusions

Candidate communication technologies for AHS applications have been presented. The issues for the design and analysis of packet radio communication systems for AHS have been discussed, and preliminary results from the performance evaluation of two packet radio technologies (Reservation-ALOHA and CDMA) have been presented. In terms of ease in expandability (i.e., integrated data traffic scenarios) they seem to be the two most promising technologies. These two schemes have also the advantage of being amenable to decentralized optimization and expansion (provided that the issues of power control and code distribution in CDMA can be resolved in a decentralized manner).

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