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SHORT-RANGE MOBILE RADIO NETWORKS FOR ROAD TRANSPORT INFORMATICS

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Abstract

The current state of work performed in PROMETHEUS/PRO-COM to define services and protocols of a short-range mobile radio network for communication between vehicles and with infrastructural equipment is presented. The network is characterized by its specific physical, media access, logical link, and network layer protocols. These protocols, which are currently under development, and the integration of the network into the variety of other existent and future networks is discussed, together with the applications to be served. Although an open network is aimed at, some applications considered have such specific demands that standard protocols for the transport and higher layers are not sufficient in their functionality to serve them.

1. Introduction

Since 1988, in PRO-COM many ideas have contributed to define a short-range mobile radio network (SR-MRN) to serve the real-time oriented applications defined by the automotive industry. Appropriate protocols were worked out to a current state, which is considered sufficiently stable to be investigated in field trials to prove their expected performance for both, vehicle-to-vehicle and vehicle-to-infrastructure communication. In terms of the Reference Model for Open Systems Interconnection (OSI) of the International Standardization Organization (ISO), new protocols were defined for the layers 1, 2, 3, and 4, which work will be summarized and discussed to some depth in the sequel.

The automotive industry and related institutions have reached a common view on the specifications of applications to be served [1]. Although they still further develop these applications and thereby modify the requirements of the future radio network, the frame is defined which has to be covered by suitable network services. Services are based on network protocols and are restricted, besides others, by technical limitations and cost considerations.

Examples of requirements not easy to meet are:
- a 100% reliable radio coverage of a given area,
- coordination and synchronization of mobile stations being within their respective interference range,
- establishment of sufficient transmit capacity and definition of a suitable frequency band,
- design of protocols for an universal, multifunctional, communications equipment for vehicles, able to support all of the known new applications, and able to be reduced in functionality to a low-cost version for introductory purposes.

In parallel to PROMETHEUS, which is part of the EUREKA Programme of the European Commission, the EC programme DRIVE was established in 1989, which from the communication point of view partly overlaps with PROMETHEUS/PRO-COM work. Both programmes, besides others, investigate the potential of communication based systems to increase efficiency and safety of road traffic and to reduce environmental pollution. The SR-MRN considered in PRO-COM must be compatible with other radio based networks developed in the various DRIVE projects for support of vehicles' traffic flow by environment based systems via both, broadcast and dialogue communication. Compatibility of these networks requires at least identical subsets of protocols. To reach that goal, PRO-COM researchers are active, too, in DRIVE I projects like VIC (vehicle intercommunication), SECFO (systems engineering and consensus forming project), and other DRIVE II projects.

2. Applications Characteristics

The PROMETHEUS Task Force Cooperative Control has produced the specifications of five applications for further investigation. The specifications are partly based on previous PRO-COM work [2]. These applications all are more or less real-time oriented:

1. Intelligent Cruise Control (ICC) monitors relevant traffic by use of the SR-MRN and supports cooperative longitudinal control between interdependent vehicles on single lanes to harmonize speeds and distance and to react to events ahead.

2. Intelligent Manoeuvering and Control (IMC) defines cooperation of vehicles in order to safeguard lane change & overtaking based on information received via the SR-MRN.

3. Intelligent Intersection Control (IIS) supports cooperative longitudinal control between interdependent vehicles at intersections to improve safety, harmonize speeds and allow better traffic conditions.

4. Medium Range Pre-Information (MRP) supplies driver and vehicle system well in advance with safety and traffic related information via the SR-MRN.

5. Emergency Warning (EW) provides information for road users about an emergency or incident case in the vicinity of the location via the SR-MRN.

Since these applications require
- a periodic distribution (10Hz) of vehicle internal system status to vehicles in the zone of relevance
- high reliable and available communication channels
- knowledge about the relative and/or absolute position of vehicles in the vicinity,
- efficient use of radio bandwidth,

the SR-MRN must
- provide reserved comms. capacity per vehicle on a periodic basis, which leads to a TDM scheme and requires local synchronism of the transmit/receive equipment,
- rely on decentral decision by the in-vehicle system, what channel is to be used for broadcast of information, leading to TDMA medium access control (MAC) protocols,
- cooperate with a suitable position finding system, which output advantageously can be used to support the MAC-protocols,
- apply transmit power control in vehicles to adapt to the actual zone of relevance (which depends on the traffic situation) and decentrally organize frequency reuse through dynamic channel assignment methods.

Since the applications can take advantage of infrastructure based communications equipment (beacons), beacons should comply to the protocols used in the SR-MRN.

2.1 System Parameters

Vehicles' vicinity includes vehicles, cyclists, pedestrians, animals and obstacles. Vehicles, which may collide or influence their respective driving behavior, belong to the same vicinity. Vicinities change with traffic conditions; vehicles in the same vicinity coordinate their driving tasks by exchange of information about their status, behavior and monitored road traffic conditions. An on board-computer evaluates all information and generates advice or intervention commands to the vehicle system and driver. The SR-MRN covers vehicles' vicinity as well as the available roadside infrastructure systems.

Extensive use of a given frequency spectrum and the propagation characteristics of electromagnetic waves result in co-channel interference and a frequent and unpredictable change of the multi-path reception situation resulting in signal fading at the receivers, besides signal shadowing, which cannot be handled satisfactorily well by any known set of radio link protocols. Signal interferences, which depend on frequency, atmospheric phenomena and conditions, fading, shadowing and, generally, nonideal transmission characteristics, restrict channel use of the SR-MRN and force allocated channels to be handover quickly when needed.

2.2 System Layout and Data

The total system capacity depends on the worst case number of vehicles clustered in a vehicle's vicinity and is estimated currently to be below 500 channels. A single channel's capacity depends on the amount of data to be transmitted per time unit and is estimated to be about 2kbit/s. Vehicles and roadside infrastructure communication systems exchange static, dynamic and situation specific data. Vehicles' mobility and the permanent changes in network topology limit dynamic data validity and make necessary a reliable error detection (and possibly forward error correction) mechanism to control the correctness of received data.

The real time constraints of some applications require use of priorities for data exchange to distinguish between urgent and other data [4]

3. System Architecture

Refering to the ISO/OSI reference model, cf. Fig.3-2.1, layers 5-7 are application dependent. Layer 4 establishes reliable connections and serves the applications with end-to-end data transport via a suitable network. Layers 3, 2 and 1 are network dependent.

With the diversity of expected road traffic applications various technologies are expected to become available to cover part of the SR-MRN. Existing and standard mobile radio networks operating in Europe, e.g. the GSM public land mobile radio network (PLMN), are considered to serve applications requiring medium to wide range communications. In addition, research is under way to extend its services by introducing a packet radio based service to support:
- infrastructure based applications, as proposed by the DRIVE/SOCRATES project [5], communications between vehicles and with beacons as supported by the CELLPAC service [6].

3.1 Integrated Architecture of the SR-MRN

In order to secure the maximum degree of integration, it is necessary that a diverse range of applications be supported by different physical communication bearers, which number has to be kept small. Layers 1 to 3 of standard communication networks can be integrated through internetworking in case of common applications. A common RTI transport protocol ensures global connectivity between applications realized from different sides and different communication networks.

SR-MRNs are still under development. A common protocol stack comprising layers 1, 2 and 3, supporting both connectionless and connection-oriented protocols, would ease share of communication capacity between the various services, speed up introduction of different applications, and save costs. Fig.3.2-1 shows the protocol stack proposed by the international PRO-COM group [7], which closely follows an earlier proposal [8]. A comparable proposal was submitted to the DRIVE community via the VIC project [39]. Above the medium, which might either use microwave or infrared, a number of parallel protocol stacks, each containing a set of layer 1 (physical) to 3 (network) protocols are shown:

- A stack for the PROMETHEUS SR-MRN providing in
  * Layer 1: Synchronization for frames/slots [9] and a capacity assignment protocol ISMA [10],
  * Layer 2a: Medium access control (MAC) protocol candidates, e.g. DMAR [11], AC/ID [12], CSAP2 [20], and others.
  * Layer 2b: A logical link control (LLC) protocol, e.g. a derivative of IEEE 802.2,
  * Layer 3: A network protocol with direction (DOR) or knowledge based routing (KOR) [15, 16],
  * Layer 3c: The ISO internetwork protocol to interconnect to the other networks, with which the SR-MRN has to interact.

- A stack for a short-range beacon-to-vehicle communications network, currently under discussion in DRIVE for payment and route guidance applications, being part of the SR-MRN

- A long-range message broadcast network, as defined by the RDS/TMC (radio data system/ traffic message channel) [14], not shown in the figure.

- the GSM PLMN, offering the CELLPAC or SOCRATES services, the X.25 packet data network and the ISDN to interconnect e.g. to traffic control centers.

Above the network layer a standard transport protocol ISO/TP4 class 0-4 might be used, or other transport protocols under discussion, like the Drive Normalized Transport Layer (DNT) protocol [24] or TCAP [29], which include additional functionality to take real-time, priority and other requirements into account, not served by the standard TP. Finally, the application layer is assumed to contain a number of specific protocols, well tailored to the Copdrive requirements [1] and to serve other applications named in the figure.

4. Early Systems

The stepwise introduction of safety-related systems is necessary due to human factors issues like acceptance and behavioural changes implications, which are as important as technical feasibility. Therefore, applications supported by an early system provide safety-related information to the driver and to rescue authorities, traffic management centers, etc. but do not contain any automatic actions. The objectives of an early system are [4]:
- avoidance of accidents,
- reduction of severity of accident related consequences,
- elimination of surprise effects,
- shortening emergency support procedures,
- contributing to traffic management and control.

Experiments with early systems are under way for applications like (dual mode) route guidance, parking management, and automatic payment [5,6,36,44,45,46, 47]. Since these systems were developed each for a dedicated application, they use simple sets of protocols, not compatible to that required for the SR-MRN. Their broad introduction might delay introduction of more sophisticated systems, since their protocols and services are expected to be unable to further develop to become compatible with SR-MRN.

We proposed to introduce the CELLPAC (CELLular PACket radio) service [6], based on the GSM cellular

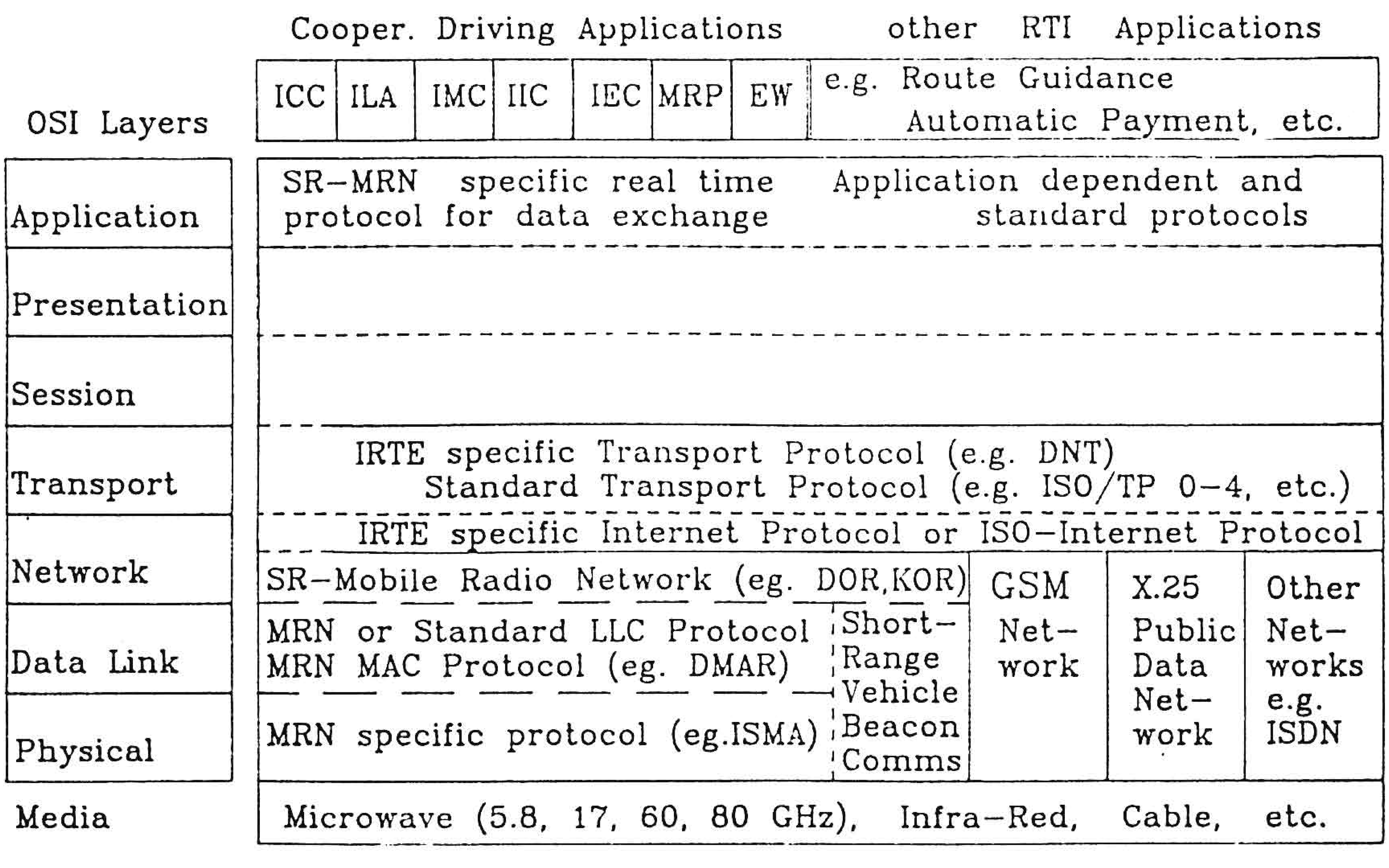

Fig. 3.2-1 Integrated Architecture of the SR-MRN and its Applications

radio network. The service is based on a slot-reservation protocol of the R-ALOHA type and supports exchange of multi-packet datagrams between mobiles in a GSM cell for point-to-point and point-to-multipoint modes of communication. The base station must repeat the data received on the uplink of a GSM traffic channel dedicated to the CELLPAC service on the corresponding downlink, whereby a local area bus-like communication network is established. In addition, the downlink channel is used to broadcast traffic control and route guidance related information.

The performance is comparable to that of the SOCRATES [6] service, which uses an R-ALOHA MAC protocol to enable mobiles to contact a traffic control center, but CELLPAC provides more functionality and shorter delay. Other beacon based systems were introduced, see [28].

Since CELLPAC and SOCRATES rely on the infrastructure provided by cellular radio operators, these systems are expected to come up in the near future. The transmit capacity provided is below 9.6 kbit/s, i.e. very limited. Other beacon based systems like ALI-SCOUT [36], are characterized by a transmission rate of 0.5 to 2Mbit/s and need establishment of a completely new infrastructure. Beacon based systems are able to serve a subset of the RTI applications under discussion only. Views are diverging currently, what introductionary steps should be taken to avoid a situation, where cars are required to carry more than one set of communication equipment, each being dedicated to one application only. A pragmatic view is, to let the market forces decide what services and related equipment will gain acceptance. However, large public investments are expected necessary to make either systems operational, which fact supports an approach of introduction of integrated instead of isolated services and protocols. This view is supported by the PRO-COM community.

5. Beacon-Vehicle Communications

Several RTI applications will be based on discontinous short-range (<100m) communications between a roadside beacon and passing vehicles, using millimeter wave, radio, or infrared transmission [36,44,45,46,47, 48].

5.1 Beacon Requirements and Limitations

The characteristics and communication requirements [39] of these RTI applications are quite different:
- One-way, periodical broadcasting (e.g Route Guidance, Driver Information)
- Two-way, broadcasting and gathering data from vehicles (e.g. Dynamic Route Guidance)
- Two-way, real-time, short-range point-to-point communications (e.g. Automatic Debiting)
- Two-way, wide-area, point-to-point (e.g. Tourist Information/Reservation, see Fig. 5.1-1)

According to these communication requirements, the beacons are expected to act as:
- Autonomous, stand-alone beacons
- Beacons connected to the infrastructure network, storing and forwarding data packets between vehicles and traffic surveillance/guidance centers or remote data bases,
- Beacons with a "mailbox" function, forwarding stored information, previously received from other vehicles or traffic/information centers, to approaching vehicles.

The advantages of beacon based systems over cellular systems (CELLPAC, SOCRATES) and RDS are:
- High transmission rates (1.25kbit/s to 10Mbit/s)
- Effective position calibration (for navigation)
- Spotwise location-oriented traffic information

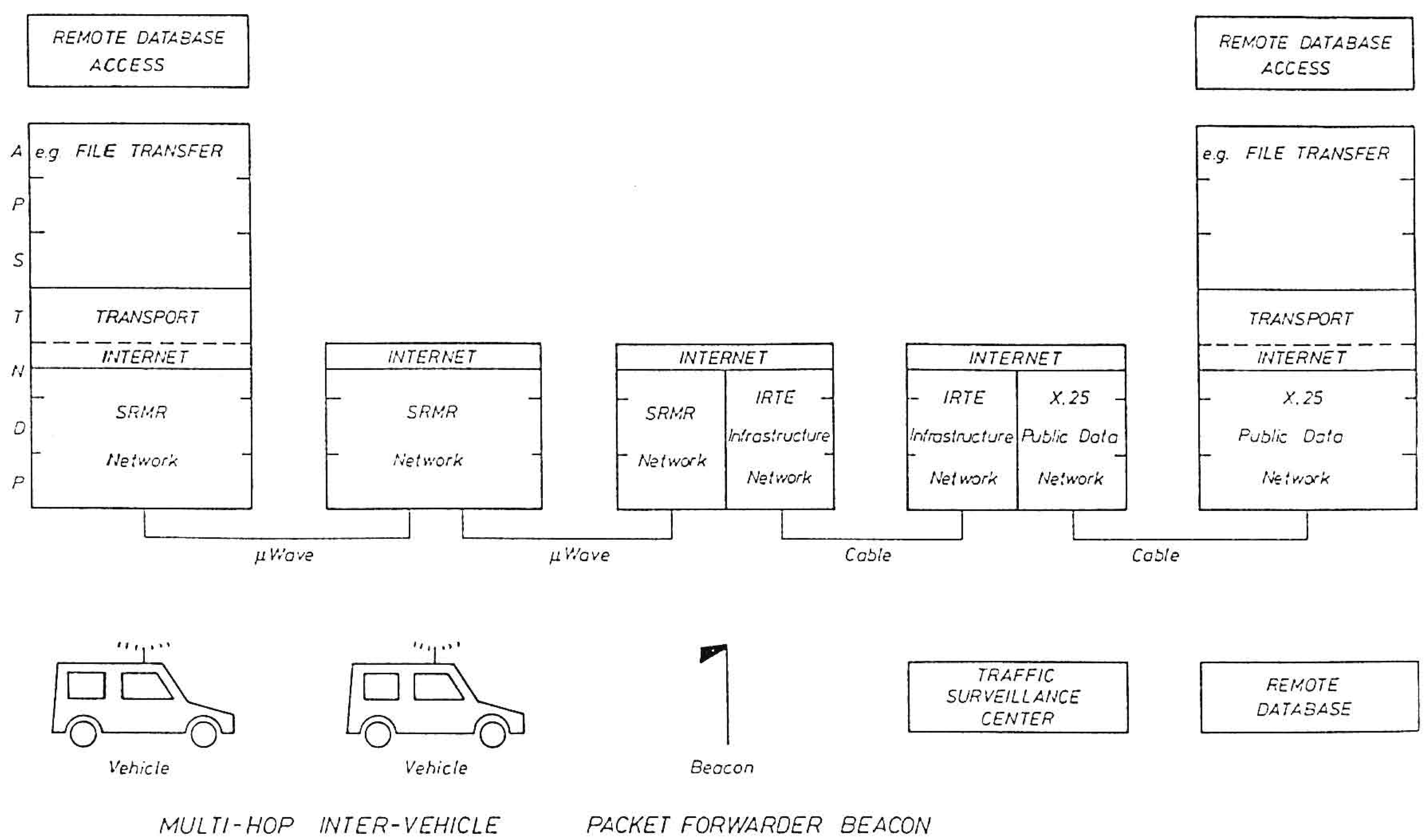

Fig. 5.1-1 Vehicle-Beacon Communications and Access to Infrastructure/Other Networks (X.25 PDN)

- Determination of vehicles on a specific road/lane (for automatic debiting, parking management, etc.)
- Measurement of vehicle/lane characteristics (for route guidance, driver information, etc.).

Disadvantages are:
- Discontinous spotwise communication
- Very limited communication zones (1m-100m)
- High system costs due to the required density of beacons, with long pay back periods.

According to the required functionality, the following beacon configurations will be used:
- Beacon with one antenna mounted at the side of a road (e.g. traffic signal), covering all lanes,
- Beacon with one antenna mounted on a gantry above the road (>5m), covering all lanes,
- Beacon with several antennas (e.g. one for each lane or more) mounted on a gantry [38,49]).

These beacon characteristics and functional requirements have an important impact on the system design and configuration (antenna characteristics, etc.) and the development of appropriate communication protocols.

5.2 Communication Protocols

Beacon based RTI applications require either one-way broadcast transmission of messages or two-way communications between beacons and vehicles. The communication might be initiated:
- by beacons only (transmission of broadcast messages or Request For Synchronisation RFS (poll) messages; unbalanced operation in normal response mode)
- by vehicles only (broadcast transmission of vehicle status messages or poll messages; unbalanced operation in normal response mode)
- either by beacons or vehicles (transmission of broadcast or poll messages; asynchronous response mode)

For multiple access to the transmission medium, either
- adaptive polling protocols (passive users are polled), or
- a combination of an adaptive polling protocol with a contention protocol (ALOHA: users are not synchronized; or Slotted ALOHA: users are synchronized into fixed-length channel time slots)

are expected to be used for beacon-vehicle communications (GANTRY [38,49], PAMELA [45], CAR GOES [44], etc.) while
- reservation protocols (e.g. R-ALOHA: time slots are organized in frames) are more suitable for vehicle-vehicle communications (DCAP [10], DMAR [11], AC/ID [12]).

6. Identification and Localization

In the SR-MRN, two classes of applications may be distinguished by their addressing mode:
- Distributive communication by broadcasting information "to anyone who is able to listen",
- Point-to-(multi)point comms. between one transmitting and other receiving vehicles.

The first is known from common radio broadcasting systems, e.g. RDS/TMC. There, neither the transmitter needs to know, which receivers are able to listen, nor where they are located.

The second mode of addressing is common in wired communication networks. There an identification procedure precedes any information exchange and the location of the partners are fixed, at least during one session. Such mode of operation is also used, when location(s) of stations are variable in time, e.g. with public land mobile radio networks (e.g. GSM).

A special situation within the second mode of addressing arises when an application needs to know the location of the partner, to whom it is communicating. Then, the process of identification of a communication partner must include determination of its localization up to the correct lane, and in case of mobility, position related data must continuously be updated. This applies to the applications defined by Copdrive [1]. Two ideas are currently investigated:

- Transponder systems, adapted to road traffic conditions, additionally offering a limited capacity for message exchange [17],
- Radio communication equipment able to measure propagation delay during information exchange [8].

Both types of systems identify and localize, and in addition are able to communicate, but have different origins and therefore are expected to solve one or the other tasks better.

Positioning is not covered by services defined for any layers of the ISO/OSI reference model. However, transmission capacity must be reserved such that data transmitted from the relative position finding system can co-exist with protocol data units of the SR-MRN. A possible solution is to do both in the same band, which requires a coordinated access to the transmission medium.

7. Protocols proposed by PRO-COM

In this chapter more detailed information is given about the status of development of protocols for layers 1 to 7.

7.1 Bit-Transmission via a Medium

Examples of work performed are definition and evaluation of:
- a method to synchronize stations up to a few microseconds to establish TDM channels using the signal of the radio clock transmitter DCF77 [9],
- the ISMA protocol to assign capacity of a radio band such that frequency of co-channel interference events, resulting from vehicles' mobility, is substantially reduced. Subframes of the ISMA frame are assigned to vehicles, moving approximately in the same direction [10].

The carrier of the radio clock DCF77 is transmitted narrow band amplitude modulated with a 1 Hz signal to periodically indicate the time reference of a second. This signal can be subdivided into intervals, according to the period of the carrier frequency. In a SR-MRN, where a range below 1km is to be covered around a vehicle by its radio equipment, any station receiving another one is able to decide, which edge of an interval was chosen by the transmitting station and might synchronize to it. This decision is possible, since the propagation delay for 1km is 3.3µs only [9].

Layer 1 protocols will still further develop, which process is accompanied by field tests, where their feasability is investigated. In addition, the radio channels' characteristics are under evaluation. This work is performed mainly by the electronics industry, together with institutes in PRO-COM. The results are expected to clarify, besides others, whether forward error correction coding (FEC) will be neccessary; the current knowledge in this field is summarized in [17,18,19].

7.2 Media Access Control (MAC) and Logical Link Control (LLC)

MAC defines access of vehicles to the radio medium to transmit data. LLC serves to establish and maintain point-to-(multi)point links, to perform flow control on a hop-to-hop basis etc. Dependent on the communications characteristics of an application to be served, properties like real-time behavior, continuity of message transmission, reliability and availability of the transmission medium, etc. are to serve by the radio communication network.

According to the limited zone of relevance typical for all applications needing vehicle-to-vehicle communication, and most of the vehicle-to-infrastructure applications, the transmission power used in vehicles is restricted. This allows the spatial reuse of radio capacity, but results in danger of interference. Solutions to that problem are the main subject of the various MAC protocol proposals, e.g.

- Protocols applying time division multiple access (TDMA) to single slots of a frame, and using reservation of free slots according to the frame period to establish continuous channels. Such protocols require local synchronism of all participating transmitters;
- Protocols needing no frame but local synchronism to access a time-slotted radio medium;
- Protocols that need no synchronism.

7.2.1 TDMA-Protocols

A TDMA protocol must respect the current channel occupancy in a sufficient wide area around a transmitter, in order to avoid undue interference to used channels, when a new channel is opened. A further development of CSAP [20] called DCAP (Decentral Channel Assignment Protocol, [21]) provides access without interference to used channels. This is performed by continuously monitoring the occupancy and receive quality of all slots in a frame and by transmitting a bitmap in each used slot, reflecting this observation. DCAP works under adaptive power control and optimizes the reuse distance of a channel. It has been formally specified and its performance extensively evaluated [10, 21, 42].

Investigations have shown [22] that continuous transmission of the bitmap is not necessary, if the DMAR (Decentral Multiple Access with Reservation) protocol on top of the ISMA protocol is applied [11]. Fig. 7.2.1-1 shows the probability P_s of an interfered channel due to mobility, conditioned that it was interference free in the frame before, over the density of vehicles (0.03 corresponds to 3600 vehicles per hour, assuming a mean speed of 120 km/h). In addition, the probability Pc of a collision during handover to a new channel is shown. What can be deduced from Fig. 7.2.1-1 is that the probability P_s of a handover request is very small, which indicates that the bitmap is not used in most of the frames.

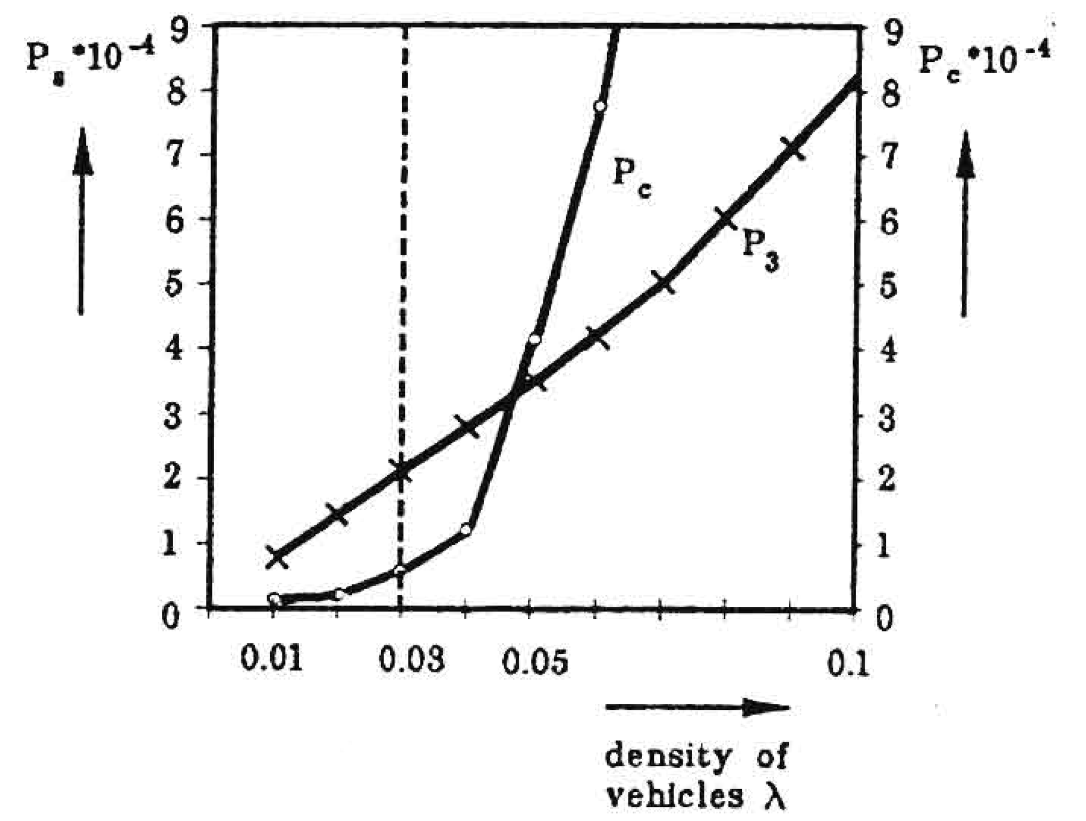

Fig. 7.2.1-1 Probabilities for handover Ps and collision P_c over vehicles' density at 120 km/h

DMAR continuously monitors all channels' quality and initiates a handover, if the receive quality fails to meet a given threshold. A bitmap-equivalent is transmitted during the handover procedure only. A vehicle requested to handover, evaluates the transmitted information, combines it with the frame occupancy observed and is able to select a free channel for future use. The interfered channel is released by leaving it unused.

DCAP and DMAR, both use information about the relative position of all other vehicles in the vicinity, which was explained necessary in chapter 6 for a SR-MRN.

Two other MAC protocols proposed are the R-BTMA [23] and the AC/ID [12] protocols. The first one relies on a busy tone transmitted via a separate frequency band during packet transmission. Any station receiving the busy tone keeps silent as long as the tone is received. The secoond protocol applies signal sensing on the transmit channel used by a station detect possible interfers. Although both protocols do not rely on a frame, and therefore cannot take advantage of the ISMA protocol, they provide channels by reservation of the n-th slot after an used slot, n being a system constant.

The MAC protocols mentioned support real-time communications and offer reliability and continuous availability of channels to different extents.

7.2.2 Slotted Channel MAC-Protocols

The S-ALOHA protocol needs no frame- but slot-synchronization of transmitters to access a radio channel correctly. It is usually applied with transponder systems to transmit their squitter and request messages [17]. This protocol was shown to be an attractive candidate when adaptive power control and/or spot beam antennas are applied [25].

7.2.3 Asynchronous MAC-Protocols

The carrier sense multiple-access (CSMA) protocol is widely used, since it operates without external synchronization and is able to organize fair share of a radio channel's transmission capacity. It has been shown that CSMA is remarkably superior to S-ALOHA, at least with omnidirectional antennas, although the property of CSMA, to not disturb an ongoing packet transmissions is partly lost, due to hidden stations [26].

This deficiency can be removed by applying a "receiver busy tone". Another approach needing support from roadside equipment is discussed in [27]. A CSMA variant called R-ISA is investigated there and shown to behave satisfactorily well.

7.2.4 Acknowledged LLC-Protocols

For applications relying on multi-hop communication, acknowledged broadcast protocols were developed [41] and analytically shown to have an exellent performance, Fig. 7.2.4-1. There, the mean number E(MQ) of received ACKs, transmitted piggy-backed as part of S-ALOHA packets, is shown over the traffic offered per station in an infinite extended multi-hop network with random placed stations, resulting in a mean number of N=6 neighbors to a station. Besides ACKs (positive acknowledgement) the protocol provides NAKs (negative acknowledgement) also, and their mean number are shown in the figure, too. The mechanism is applicable to framed systems, and outperforms the well known Echo ACK protocol.

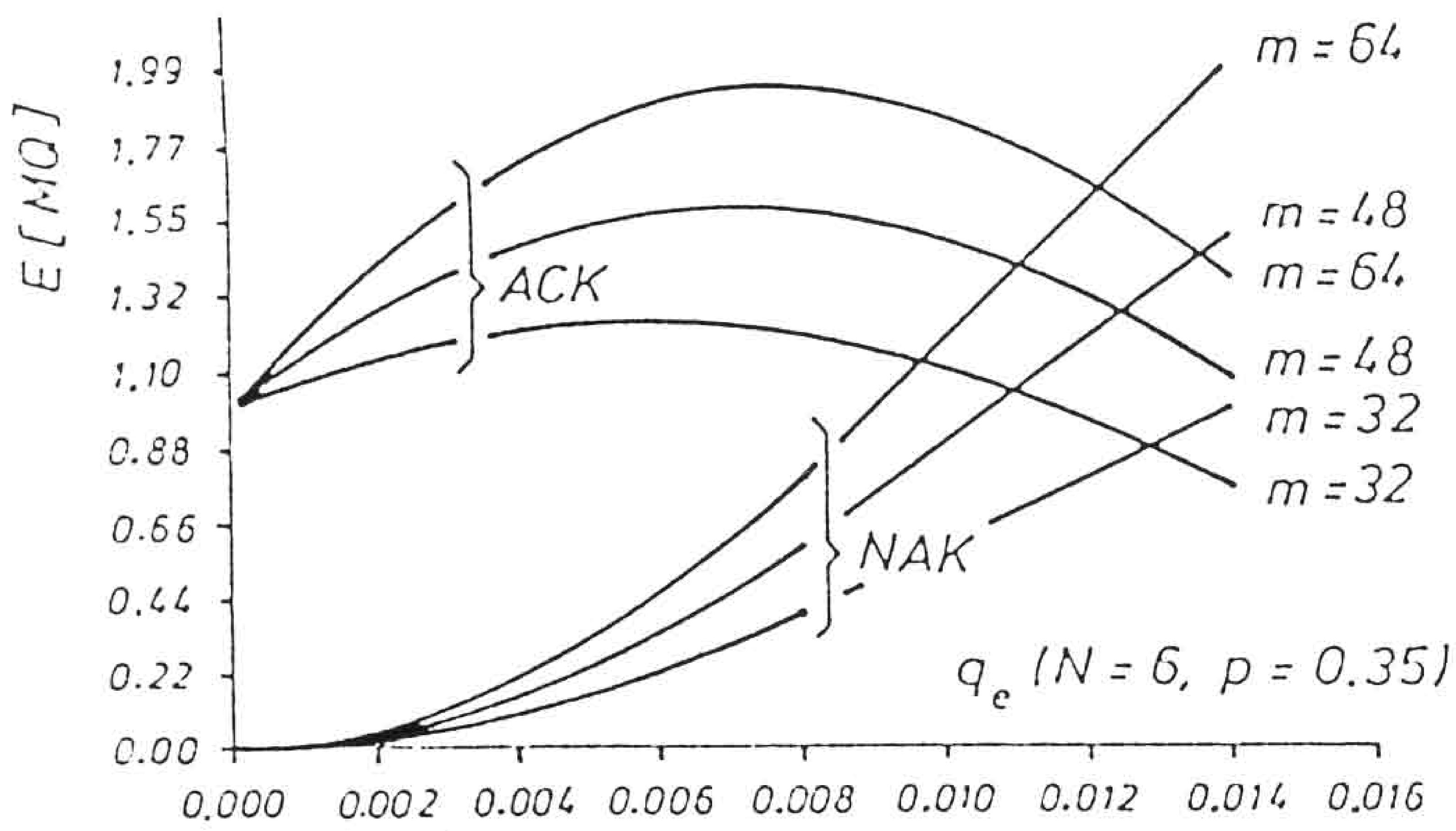

Fig. 7.2.4-1 Mean number of positive (ACK) and negative (NAK) acknowledgements per transmitted packet over offered traffic in an S-ALOHA multi-hop network.

7.3 Network Control and Internetting

In layer 3, besides others, point-to-(multi)point connections are established, maintained and released and broadcasting is organized. Packets are routed via one or more networks, address resolution and network flow control are performed, and internetworking services are offered. Basic routing concepts for vehicle-to-vehile and vehicle-to-infrastructure communication were defined in [15]. Knowledge based routing concepts taking into account traffic signs and extrapolation from current speed and travel direction of a vehicle to forecast the future network topology were developed and investigated [16,39]. A proposed routing protocol Marion [40] was shown to be inferior [37] to the DOR protocol [15], see Fig.7.3-1.

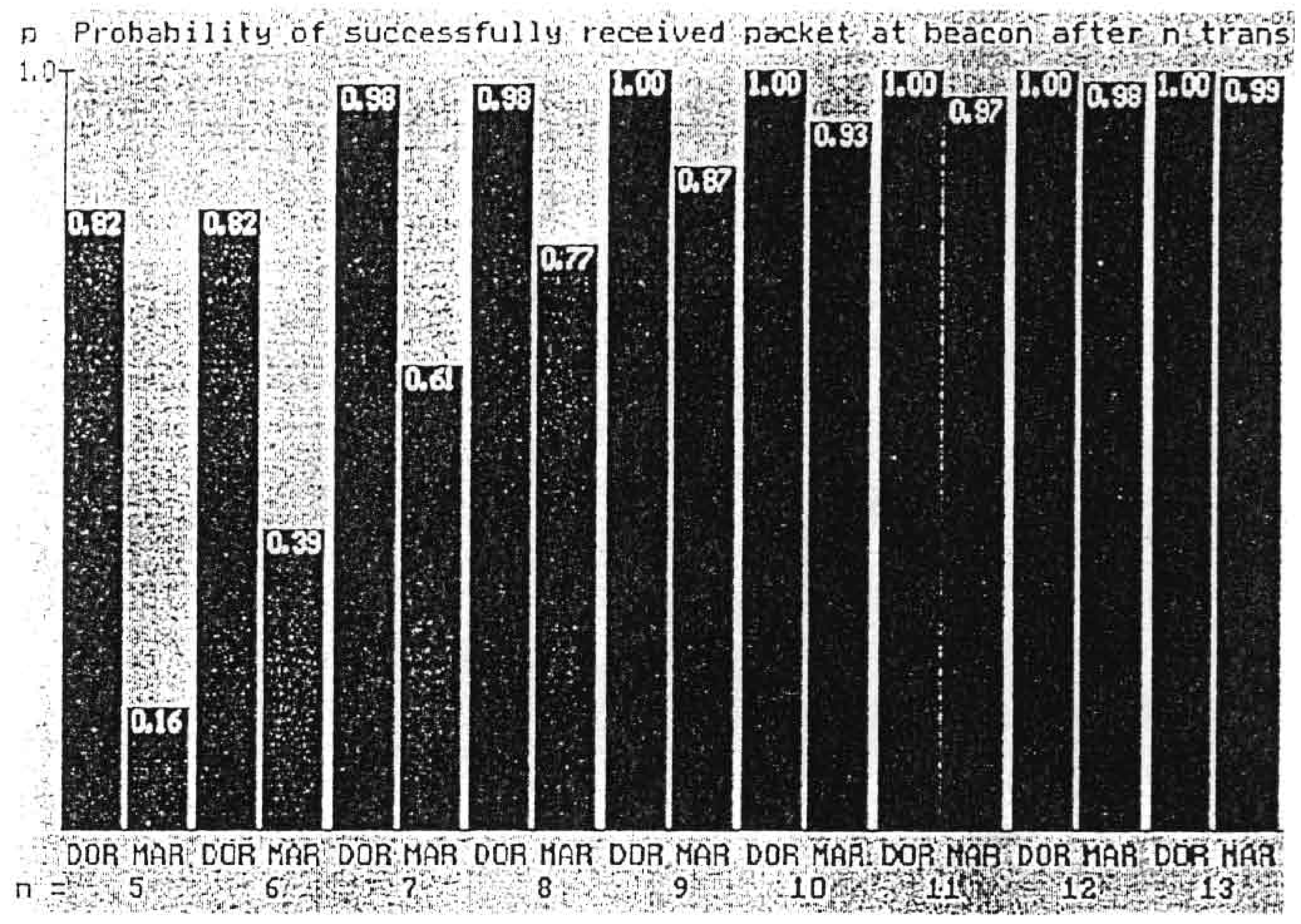

Fig. 7.3-1 DOR Routing Perfomance versus MARION Multi-hopping to Next Beacon (5 hops): Probability of successfully received packet at beacon after n transmissions.

7.4 End-To-End Message Transport

Message transport, possibly via a sequence of network nodes, is performed by establishing and maintaining a sufficient number of end-to-end connections and supervising the correct sequence of packets in a message. Multiplexing of data streams issued by different applications in a vehicle using the same connection, and priority controlled access to such connection are the main contributions of the TCAP protocol [29]. A complementary technique is splitting of messages to be transmitted via parallel connections, and recombining them at the receiving vehicle. Such a transport service is useful to enhance the transmission capacity of a layer 4 connection through parallel channels, if the throughput of one is too small. This is expected to happen with beacon-vehicle communication, if files (route updates) from a roadside beacon are to transmit. Such a transport protocol was developed at our institute.

7.5 Application Oriented Layers 5 to 7

The work performed to support PROMETHEUS applications by specifying communication characteristics and data structures is summarized in [2]. There, a hierarchy is presented where applications are successively refined until they can be defined in terms of basic functions. As communication aspects are the main subject of interest, applications and basic functions are supplied with characteristics, which will eventually define the network design. This work was extended by [30]. In [31], formal description techniques were introduced to combine the basic functions mentioned to perform a more sophisticated service "overtaking".

Work to specify application layer services and protocols by the PRO-COM institutes is concentrated on defining basic mechanisms, elements and structures. They are expected to be applicable to form a tool box for definition of any application protocol, as soon as detailed descriptions of its scope and requirements are available from the automotive industry. Integration of components like sensors, actuators, local databases, driver interfaces, external communications equipment, etc. into an overall SR-MRN system is presented in [32].

8. Formal Specification Methods

Formal specification methods are state-of-the-art techniques to define protocols and services by use of standardized languages. The method is not limited to communication protocols. One candidate specification language is SDL (system description language) supported by CCITT. It has been selected in 1989 by the German PRO-COM institutes as their standard method. Another candidate, being supported by the Swedish PRO-COM group [33], is LOTOS (language of temporal ordering and specification) standardized by ISO in 1986.

Both, SDL and LOTOS, were designed for the specification of protocols. SDL has been extensively used, whilst LOTOS is just being introduced. This situation is also reflected by the maturity of tools available to date for the languages. An advantage of SDL is, that due to its programming language appearance, combined with a graphical mode of representation (like flow charts), it is easier to learn and apply than LOTOS, which is based on algebraic expressions. It is expected, that both languages will be used in parallel which is not a severe problem as far as communication experts are involved.

9. Migration from Standardardized Services and Protocols to the SR-MRN

To date, neither a complete set of protocols and services has been agreed for the SR-MRN to cover the 7 layers of the ISO/OSI model, nor were the proposed protocols implemented for use on a real host. To support their early exploration during field trials, it was proposed to embed them into the INTERNET protocol family (TCP/IP, UDP, SMTP, FTP etc.), which is widely used by computer communication specialists all over the world [8].

According to that idea, the correct functioning of proposed SR-MRN protocols can be investigated as soon as they are available. The Internet protocols are assumed to be step by step substituted by dedicated SR-MRN protocols, until the complete SR-MRN protocol stack is implemented. This introductionary strategy not only permits the substitution of the Internet protocols, layer by layer, by newly developed SR-MRN protocols, but also by ISO/OSI protocols, if advantageous. A similar strategy is also used by the DRIVE/UROP (Universal ROadside Processor) project.

10. Operating System Aspects

The services and protocols discussed so far are supposed to be implemented on a vehicle-internal host, serving both communication and vehicle-oriented applications running under a multi-tasking operating system. As the lower layer protocols require a real-time supporting executive, operating systems like UNIX or OS/2, are not applicable, since they use time-slots to provide multi-tasking and are unable to quickly react to an interrupt. Research is needed to clarify, whether a descendant of such widely used operating systems, or a real-time executive will be the better approach.

11. Simulation Tools

Currently, a number of simulation tools are used in the various PRO-COM institutes. These simulators address specific problems, and are neither sufficiently well documented to be used by third parties, nor flexible enough to be adapted to other problems. The costs invested in such simulators, sometimes were overestimated. Nevertheless, the initiative [34] to harmonize and possibly integrate them and combine them with the existent simulators of global vehicle flow on roads/highways into a more universal tool, is interesting. Whether this will happen or not, the SIMCO simulator [35,38] is still further developed at our institure to become an universal tool for investigation of applications on top of the SR-MRN. SIMCO comprises both, in detail modelling of communication protocols [49] up to layer 7 of the SR-MRN and a very realistic model of the mobility of vehicles.

12. Conclusions

This paper tried to discuss all communication related aspects of a future SR-MRN, especially considering its protocols and services, and to evaluate and compare the proposed solutions offered by the involved institutes. Emphasis was placed also on putting the various beacon based systems into relation to the SR-MRN. From this overview it should be clear that neither of the proposed networks based on vehicle-to-beacon communication is sufficient to serve the Copdrive applications. Our conclusion is, that a SR-MRN network integrating vehicle-to-vehicle and vehicle-to-beacon communication is the most preferable solution and able to meet the requirements.

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