14. Statusseminar "Kraftfahrzeug und Straßenverkehr" 13.-15. Mai 91, Dresden.

Short-Range Mobile Radio Networks*

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SUMMARY: The current state of work performed in PROMETHEUS/PRO-COM to define services and protocols of a short-range mobile radio network (SR-MRN) 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 supposed to be served. Although an open network is aimed at, some of the applications considered have such specific demands that known 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 lower 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 on 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,
- perfect coordination and synchronization of mobile stations being out of their respective receive 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 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 an EUREKA programme of the European Commission, the 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

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safety of road traffic and reduce impact on environment. The SR-MRN considered in PRO-COM must be compatible with other radio based networks developed in the various DRIVE projects to support vehicles' traffic flow by environment based systems via both, broadcast and dialogue communication. Compatibility of networks requires at least identical subsets of protocols. To reach that goal, PRO-COM researchers are active, too, in DRIVE projects like VIC (vehicle intercomms.) and SECFO (systems engineering and consensus forming project).

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]. All of these applications are judged to be 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) describes cooperation of vehicles in order to safeguard lane change & overtaking based on information received via the SR-MRN.
3. Intelligent Intersection Control (IIS) intends to support 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 of safety and traffic related situations with information via the SR-MRN.
5. Emergency Warning (EW) provides road users with information about an emergency or incident case in the vicinity of the location via the SR-MRN.

Since these applications require

a) a periodic distribution of vehicle internal system status to vehicles in the zone of relevance (e.g. with 10Hz repetition rate),
b) communication channels with high reliability and availability,
c) knowledge about the relative or absolute position of vehicles in the vicinity,
d) efficient use of the available radio frequency resources,

the SR-MRN must

a) 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,
b) rely on decentral decision by the in-vehicle system, what channel is used for broadcast of information, leading to TDMA medium access control (MAC) protocols,
c) cooperate with a suitable position finding system, which output can advantageously be used to support the MAC-protocols,
d) 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 these 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 structure 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. The system data comprise private, resident, acquired and processed data. Resident data are fixed or dependent on driver or vehicle features or characteristics. Data acquired from other vehicles, roadside infrastructure systems and the neighborhood are highly dynamic and result from monitoring the neighborhood using appropriate technologies like sensors and artificial vision. On-board computers process data, Fig. 1, for informative and/or control related applications [4].

The system performs real-time data acquisition, computing and control. Computing includes,

- time-based computing to key its operation to time in the real-road world;
- sensor-based computing to monitor and measure (passive) the states of the traffic process;
- actuator-based computing to control or manipulate (active) the driving performance process;
- interactive computing to monitor responses, which contain data with certain time constraints e.g. position direction and speed of a vehicle in road traffic.

3. System Architecture

Refering to the ISO/OSI reference model, cf. Fig. 2, 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. Layer 3 handles internetworking and routing and is network dependent as well as layers 2 and 1. Layer 2 transfers data reliably and provides access methods for transmission. Layer 1 handles bit transmission via the communication medium.
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 the services offered by the GSM PLMN by introducing a packet radio based service with small transmit capacity demands to support

- infrastructure based applications, as proposed by the DRIVE/SOCRATES project [5],
- comms. between vehicles and with beacons as supported by the CELLPAC service [6].

Static Data	Dynamic Data	Processed Data
VEHICLE: Identity Type Size Performance	VEHICLE: Position Speed Direction Status	VEHICLE: Position, Direction, Speed Limits, Risks Control, Monitor
ROADSIDE: Identity, Position,	ROADSIDE: Status,	ROADSIDE: Monitor,
ROAD: Identity, Topology, Geometry, Regulations,	ROAD: Surface, Weather, Traffic, Emergency,	ROAD: Conditions, Limits, Risks, Monitor,
DRIVER: Destination, Private, Ability,	DRIVER: Activities, Status,	DRIVER: Monitor, Advice,
EQUIPMENT: Type.	EQUIPMENT: Status.	EQUIPMENT: Monitor, Control,

Fig. 1 Basic Information Types

3.1 Dedicated Architecture

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 are well defined and can be integrated only through internetworking in case of common applications. A common RTI transport protocol ensures global connectivity between all applications realized from different sides and different communication networks. Short-range applications differ in communication requirements. Safety-related Copdrive applications are best served through connectionless multicast communication. Some infrastructure based applications, like automatic payment systems require connection-based communication in order to ensure financial transfers accurately. The same applies to other SR-MRN applications like dynamic route guidance.

3.2 Integrated Architecture of the SR-MRN

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. 2 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],
  * 2a medium access control (MAC) protocol candidates, e.g. DMAR [11] and DMAP [12]. Other protocols are also considered, which still are developed and not published, like B2TDMA and Busy, or are applicable to limited applications only, see chapter 6.
  * 2b a logical link control (LLC) protocol, e.g. a derivative of IEEE 802.2,
  * 3 a network protocol with direction (DOR) or knowledge based routing (KOR) [15, 16],
  * layer 3c the internetwork protocol according to ISO, that serves to interconnect to the various 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 PLMN defined by GSM of CEPT, offering the CELLPAC or SOCRATES services [5],
- the X.25 packet data network and the ISDN to interconnect e.g. to traffic control centers.

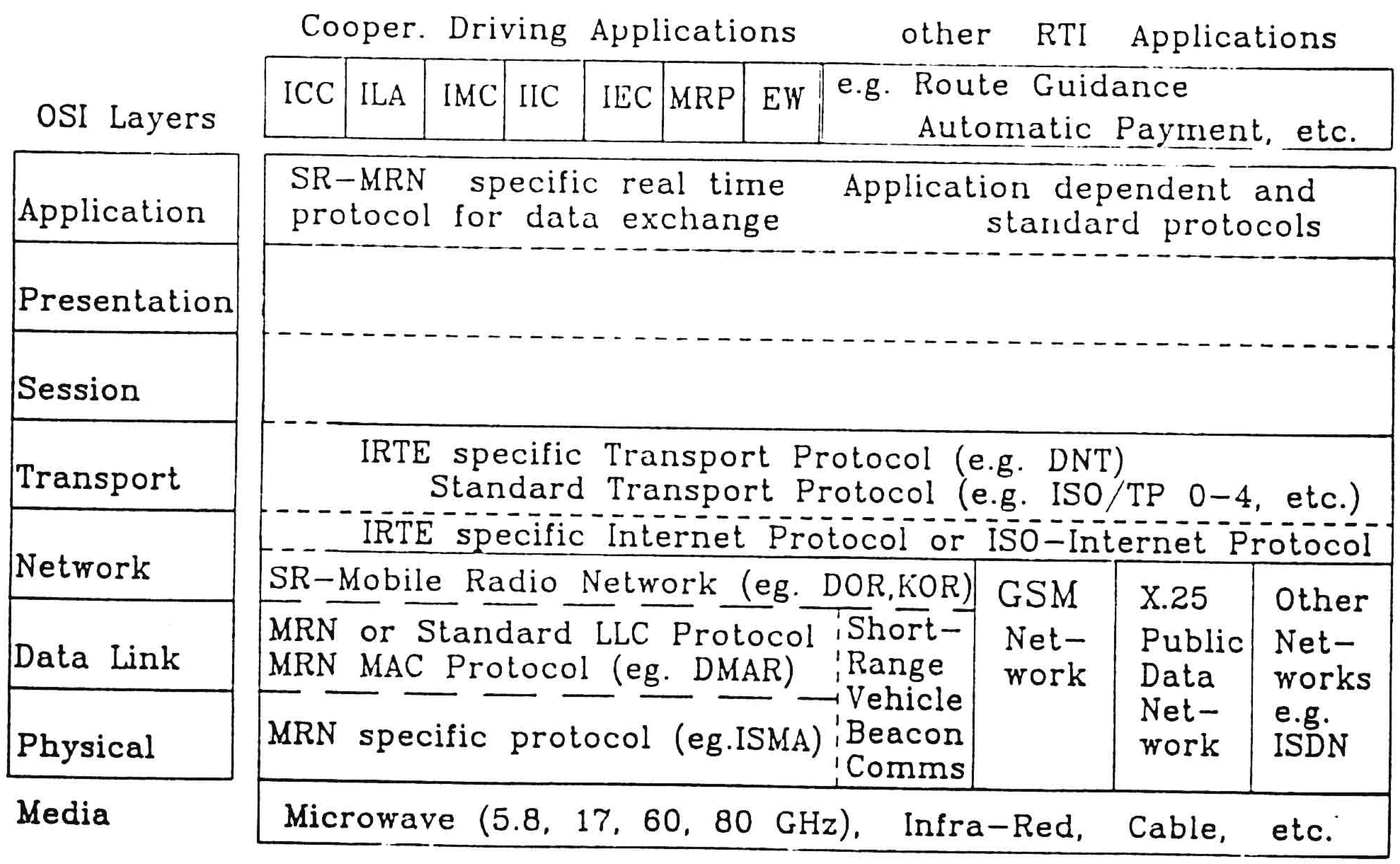

Fig. 2 Integrated Architecture of the SR-MRN and its Applications

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 [49], which includes 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.

A generic comunication protocol reference model for interconnection of networks, dedicated to various applications, is shown in Fig. 3 [8].

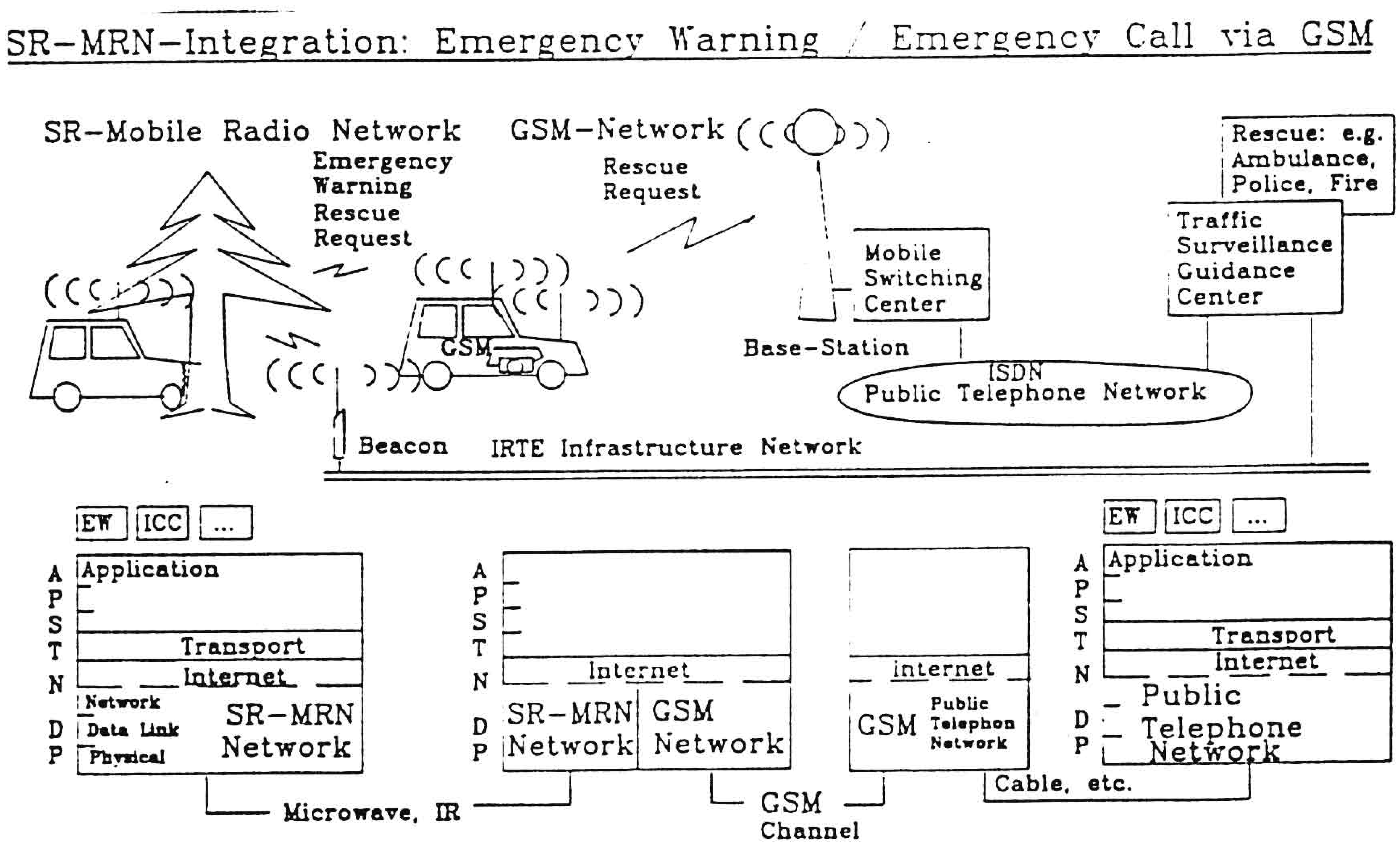

Fig. 3 Generic Reference Model for Intervehicle and Vehicle-to-Infra Communication

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

- avoidance of accidents,
- reduction of severity of accident related consequences,
- elimination of surprise effects,
- shortening emergency support procedures,
- contributing to traffic management and traffic control.

Experiments with early systems are under way for applications like (dual mode) route guidance, parking management, and automatic payment [5,6,44,45,46,47]. 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. A broad introduction of such systems might delay the introduction of more sophisticated systems, since their protocols and services are expected to be unable to further develop to an extent needed in a SR-MRN.

We proposed to introduce the CELLPAC (CELLular PACket radio) service [6], based on the GSM cellular 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 CELLPAC protocol has been formally specified in Estelle and simulated in a mobile environment to analyze its performance. Fig. 4 shows throughput and delay of mobile originating messages, using the uplink, over the total offered traffic. The number of bursts per message (a burst fits into a GSM TDM-slot) is a parameter. These results are applicable, too, to characterize the SOCRATES service which uses an R-ALOHA MAC-protocol to enable mobiles to contact a traffic control center point-to-point. Other beacon based systems are introduced, see [28].

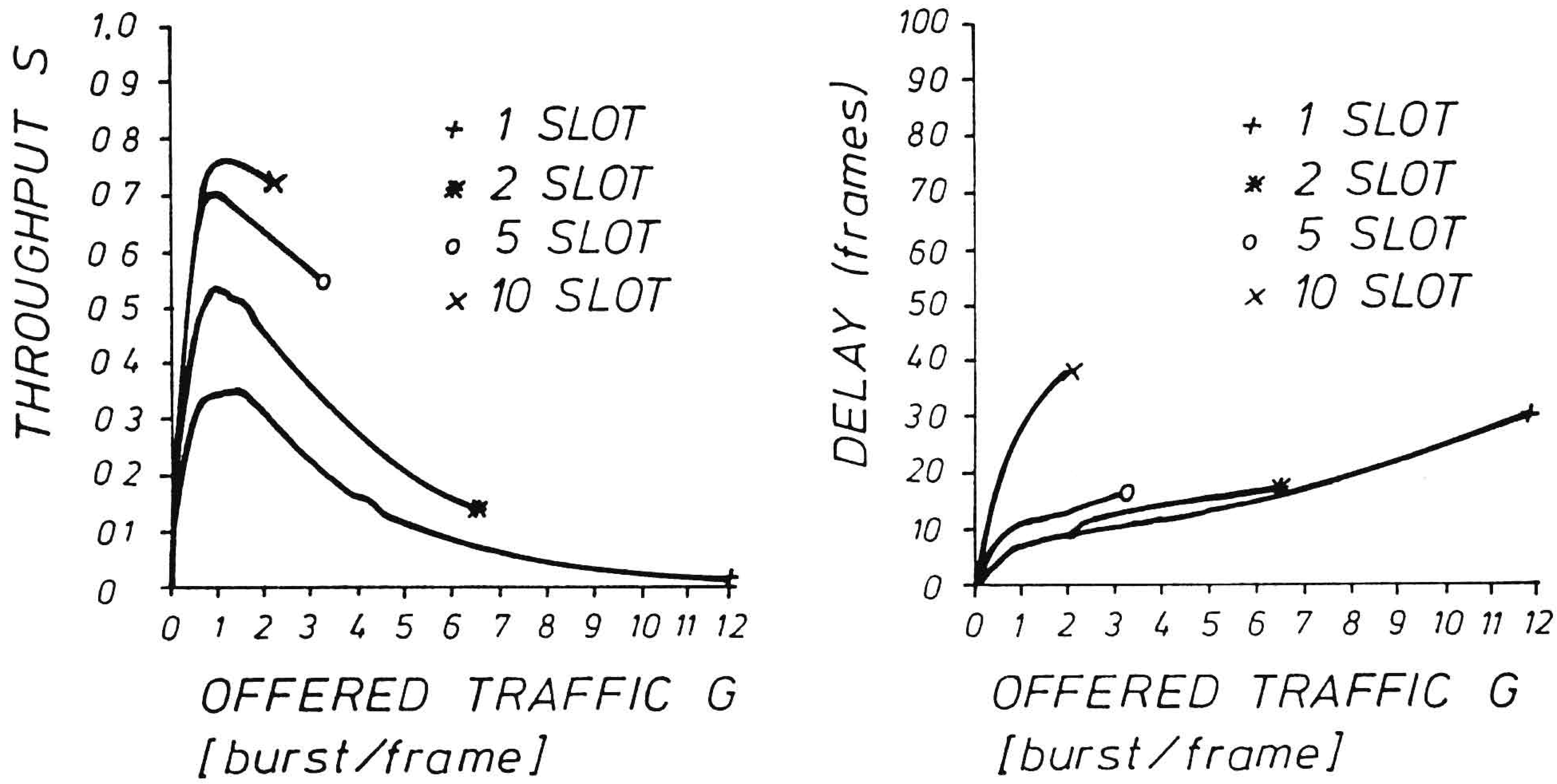

Fig. 4 Throughput and delay of mobiles originated messages over offered traffic [6]

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 [49], 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. Identification and Localization

In the SR-MRN, two classes of applications may be distinguished by their addressing mode:

1. distributive communication by broadcasting information "to anyone who is able to listen",
2. 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 being enhanced to measure propagation delay during the ongoing 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.

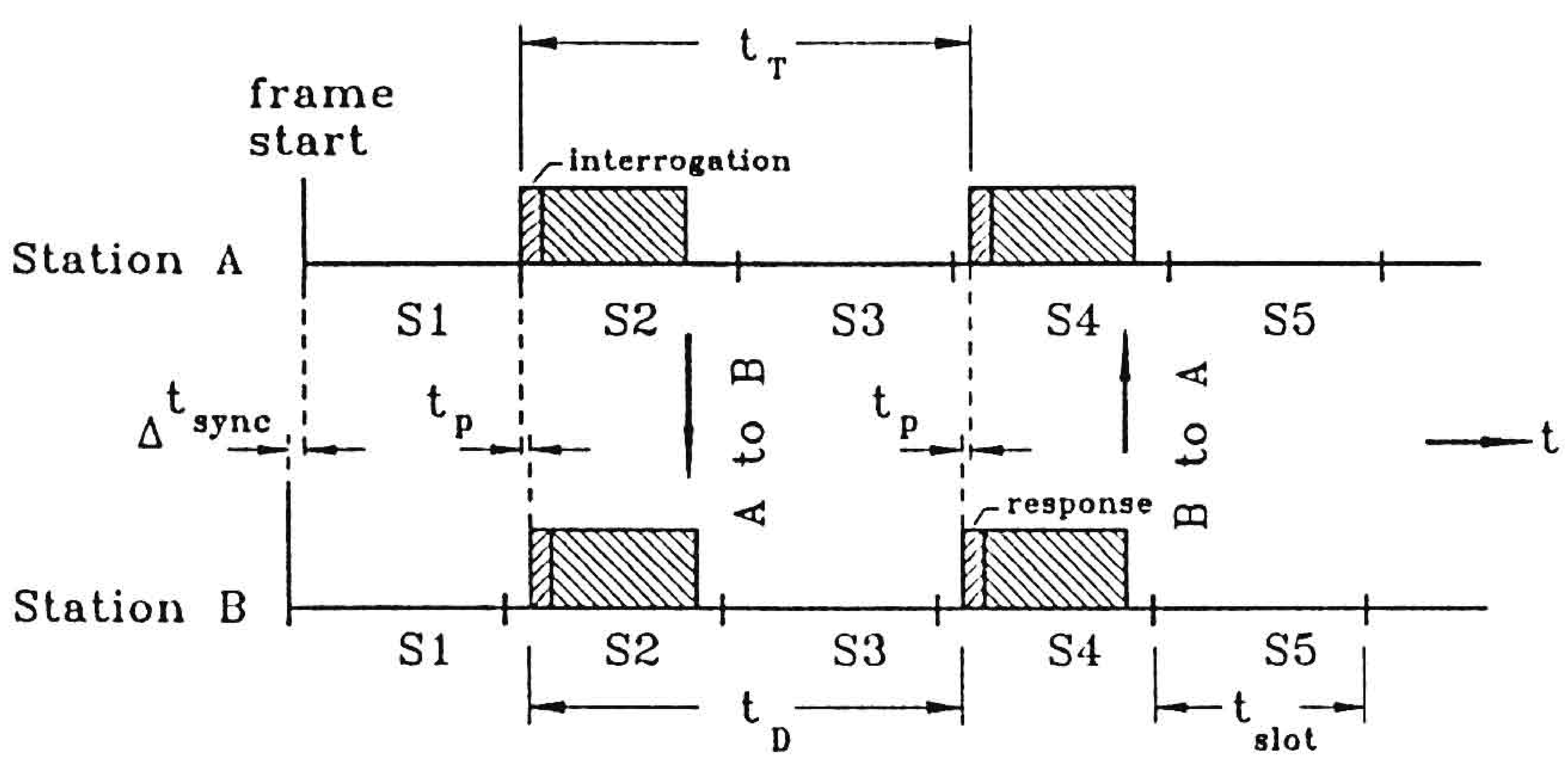

Fig. 5 Integration of distance measurement and communication in COMBINE

Fig. 5 schematically shows distance measurement as part of communication in the proposed COMBINE system [8]. A vehicle, which was interrogated by another to reply to a distance measuring signal, must not reply immediately, but after a suitable time delay, which length must be communicated in the response packet. A separated frequency band for distance measurement is not needed with this mechanism. In the figure, an interrogation by station A reaches station B after the propagation delay t_p, and is answered in the TDMA channel corresponding to slot S4 used by station B, after a delay t_D, which is an integer multiple of a slot length. Station A is then able to calculate the round trip propagation delay $2t_p + t_D$.

6. Protocols proposed by PRO-COM for various layers of the ISO/OSI model

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

6.1 Layer 1: Transmission of Bits via a given Medium.

Examples of work performed are definition and evaluation of:

A. A method to synchronize frames and slots up to a few microseconds to provide TDM communication channels using the signal of the radio clock transmitter DCF77 [9],

B. 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. Communication channels 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. For further details see [9].

The TDMA frame to be used with the ISMA-protocol is shown in Fig. 6. It contains e.g. four subsections for four directions, into which vehicles might move. A fifth subsection is reserved for packet radio access protocols, e.g. for communication between a beacon and a vehicle [9].

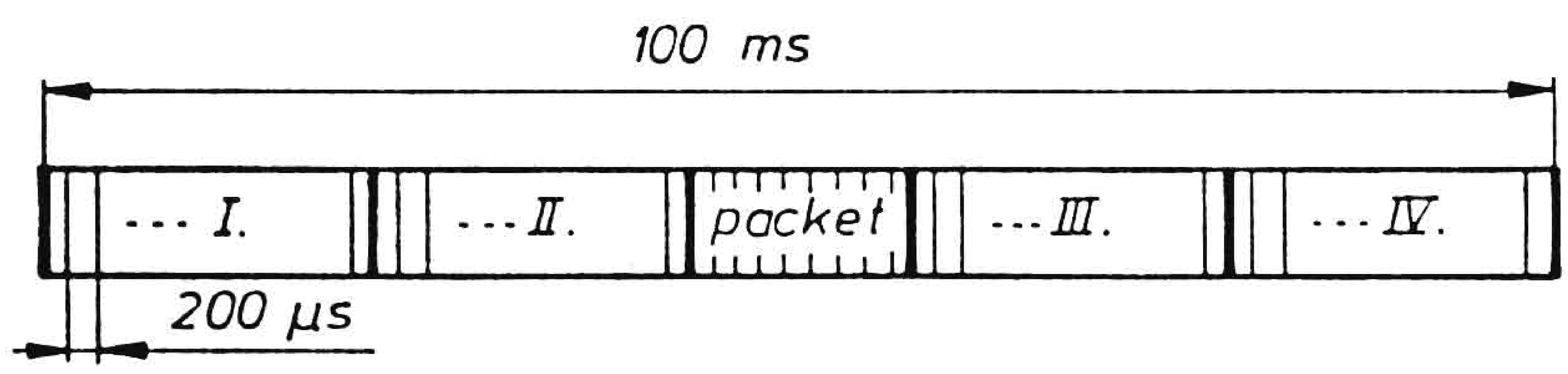

Fig. 6 A frame with subsections, assigned to directions into which vehicles move

The protocols are currently further developed, which process is accompanied by field tests, where their feasability is investigated. In addition, the radio channels' characteristics, when operated in frequency bands of interest, are under evaluation. This work is performed mainly by the electronics industry, together with institutes in PRO-COM. The results are exspected to clearify, besides others, whether forward error correction coding (FEC) will be required; the current knowledge in this field is summarized in [18], [19].

6.2 Layer 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. This is not an easy task, e.g. functions 1. to 3. of Copdrive [1], need highly reliable radio channels.

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 between ongoing communications. Solutions to that problem are the main subject of the various MAC protocol proposals, e.g.

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

6.2.1 MAC-Protocols using synchronous channels for communication

A MAC protocol must take into account 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. Since CSAP [20] is no longer considered sufficient, DCAP (decentral channel assignment protocol) [21] remains as a possible solution, which provides local access without interference to used channels. This is performed by continuously monitoring the occupancy and receive quality of all channels seen by a vehicle and by transmitting a bit map in each used slot. DCAP is able to work under adaptive power control and to improve channel economy by optimizing the reuse distance of a channel. It has been formally specified and its performance extensively evaluated [10, 21, 36].

Investigations have shown [22] that continuous transmission of the bit map might not be necessary, if the DMAR (decentral multiple access with reservation) protocol on top of the ISMA protocol is applied [11]. Fig. 7 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 120km/h). In addition, the probability P_C of a collision during handover to a new channel is shown. What can be deduced from Fig. 7 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.

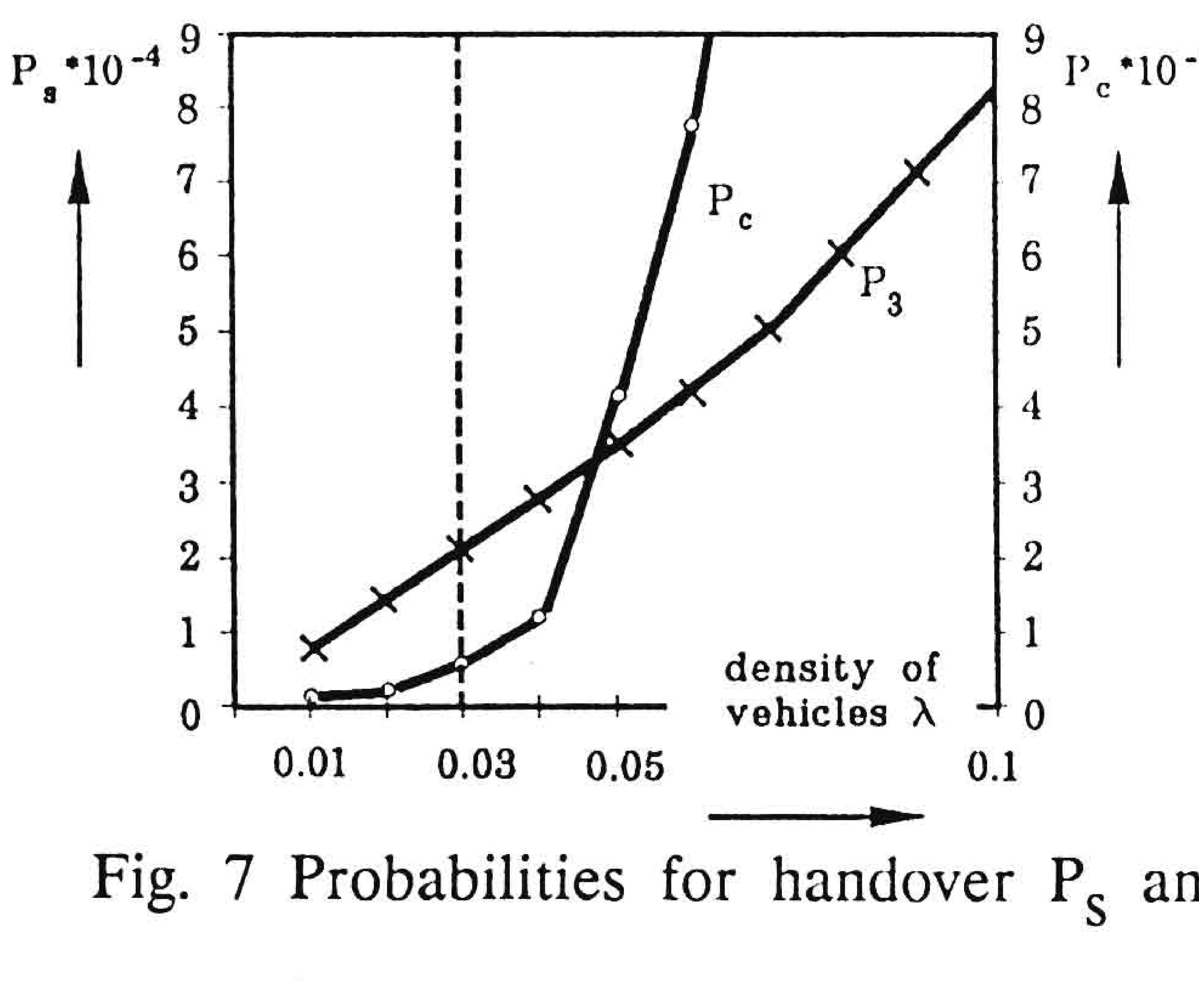

Fig. 7 Probabilities for handover P_S and collision P_C over vehicles' density at 120km/h

DMAR takes advantage of this fact: A vehicle's receiver continuously monitors the channels' quality and initiates a handover request to the respective transmitter, if the receive quality of its channel fails to meet the needed quality threshold. A bitmap-equivalent is transmitted during the handover procedure of DMAR only. A vehicle requested to handover, evaluates the transmitted information, combines it with its local view and selects a free channel, which promptly is used for future transmissions. The used channel is released by simply leaving it

unused. This mechanism is to some degree comparable to what is called a handover in the GSM PLMN, applied to decentral operation in the SR-MRN. DMAR is known to outperform DCAP, but no results were published to date.
Both, DCAP and DMAR, use, if available, information in a vehicle about the relative position of all other vehicles in the vicinity, which was explained necessary in chapter 5 for a SR-MRN. Two other proposed MAC protocols are the R-BTMA [23] and B2TDMA protocols [24]. Both rely 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 two protocols differ in the source, where the busy tone is generated and the power budget applied. 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.
The MAC protocols mentioned in this chapter support real-time communications and offer reliability and continuous availability of channels to a different extent.

6.2.2 Slotted MAC-Protocols

A well-known protocol, needing no frame- but slot-synchronization of transmitters to access a radio channel correctly, is the S-ALOHA protocol. It is usually applied with transponder systems to transmit their squitter and request messages. This protocol has been carefully investigated and was shown to be an attractive candidate in situations, where adaptive power control and/or spot beam antennas are applied [25].

6.2.3 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 the S-ALOHA protocol, at least with omnidirectional antennas, although the property of CSMA, to not disturb an ongoing packet transmissions is partly lost, due to the hidden station problem [26].
This deficiency can be removed by applying a "receiver busy tone". Another approach needing support from roadside equipment is described in [27]. A CSMA variant called R-ISA is investigated there and shown to behave satisfactorily well.

6.3 Layer 3: Network Control and Internetting

In layer 3, besides other, 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].
For applications relying on multi-hop communication, acknowledged broadcast protocols

were developed [41] and analytically shown to have an exellent performance, Fig. 8. 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, too.

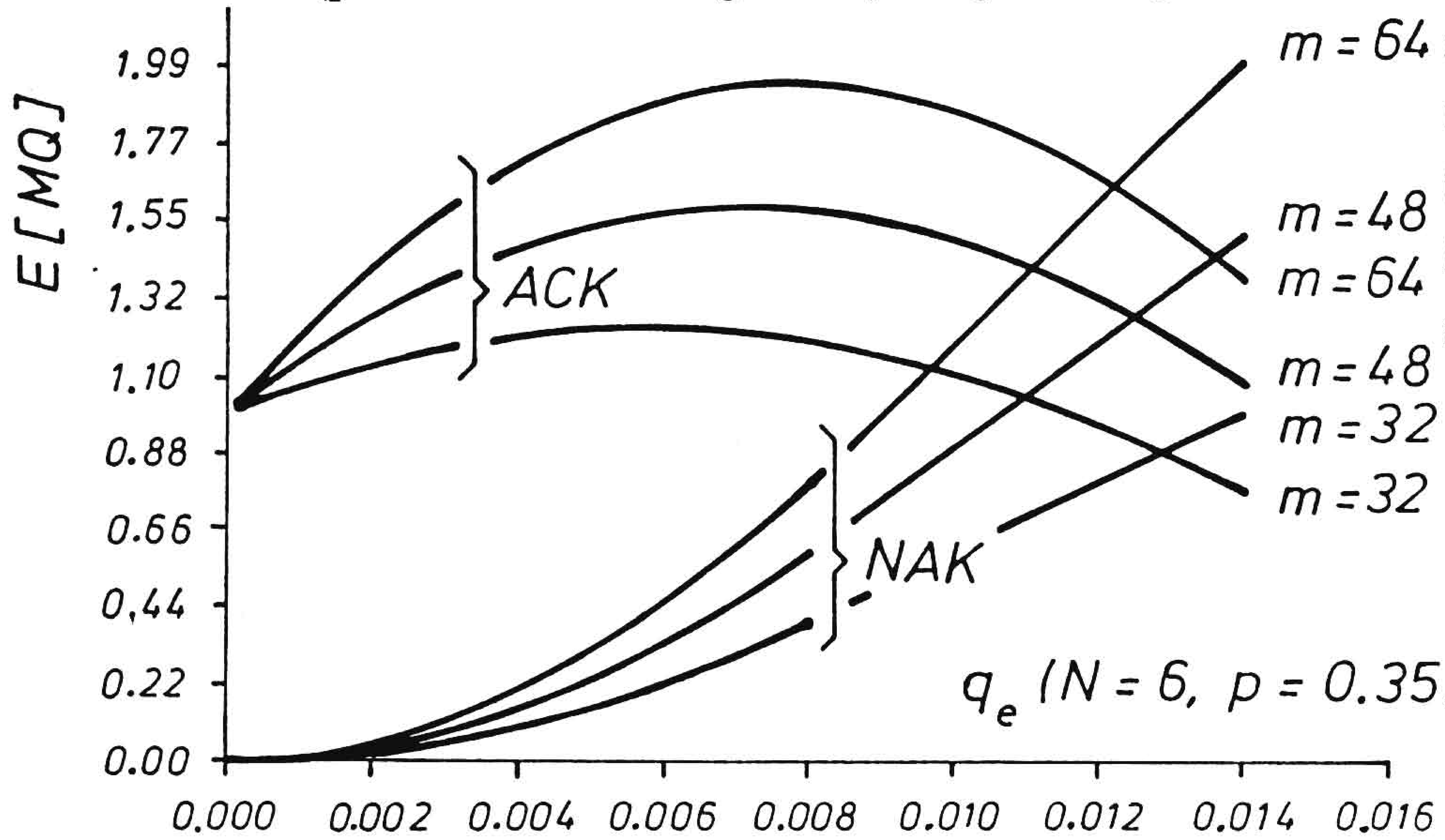

Fig. 8 Mean number of positive (ACK) and negative (NAK) acknowledgements per transmitted packet over offered traffic in an S-ALOHA multi-hop network.

6.4 Layer 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 [48].

6.5 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. In [32] an approach to integrate components like sensors, actuators, local databases, driver interfaces, external communications equipment, etc. into an overall SR-MRN system is presented.

7 Formal Specification Methods for PROMETHEUS Services and Protocols

Formal specification methods are state-of-the-art techniques to describe 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 and this is judged not to be a severe problem as far as communication experts are involved.

8 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 early exploration of protocols 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 introduction 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.

9 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 clearify, whether a descendant of such widely used operating systems, or some real-time executive will be the better approach.

10 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 was 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 quite interesting. Whether or not this will happen, the simulator SIMCO [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 up to layer 7 of the SR-MRN and a very realistic model of vehicles' mobility.

Conclusions

This paper has tried to present all of the 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, which is required to serve the applications defined by Copdrive. 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. Apparently, a SR-MRN network integrating vehicle-to-vehicle and vehicle-to-beacon communication is the only possible solution to meet the requirements.

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