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COMBINE: MODULAR SYSTEM FOR COMMUNICATION AND RELATIVE POSITIONING FOR SHORT-RANGE MOBILE RADIO NETWORKS

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Abstract

Equipment for Short-Range Mobile Radio Networks (SR-MRN) is described covering the demands of any communication related RTI (Road Traffic Informatics) application supporting driver information and therefore traffic safety and efficiency. One important feature is integration of vehicle-to-vehicle and vehicle-to-infrastructure communication into one network, thereby minimizing the need for protocol conversion between the short-range radio and any connected long-range infrastructural communication network to the smallest degree possible. A second attractive property is integration of communication, identification and relative positioning into one system such that the highest possible spectrum efficiency is reached. A third nice feature is the ability to configure the equipment properly to serve just these RTI applications being of importance to some user group aimed at. Thereby, the system proves to be highly cost efficient. Our proposal is based on careful analytic and simulative analysis, being still under way, to secure the functionality of the newly developed lower layer protocols. The higher layer protocols are mainly based on widely used standard protocols and cover any services known for computer communication networks.

1. Introduction

To date, the RTI applications are not specified in sufficient detail, such that the related performance figures required from the radio communication network can be derived, definitively. What, however, can be defined are sets of applications requiring related performance attributes, which approach is useful to define well adapted options of the communication equipment for the respective purposes. The following list reveals the considered RTI applications:

- Obstacle Detection (OD) discriminates objects and evaluates them as obstacles for collision avoidance.
- Monitoring Environment/road (ME) acquisits information on the status of the external environment of a vehicle.
- Intelligent Manoeuvring and Control (IMC) describes cooperative actions of vehicles in order to safeguard lane changes and overtakings, based on information transmitted via the short-range mobile radio network (SR-MRN).
- 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 speed and distance and react to events ahead.
- Intelligent Intersection Control (IIC) intends to support cooperative longitudinal control between interdependent vehicles at intersections to improve safety, harmonize speeds and allow better traffic conditions.
- 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.
- Emergency Warning (EW) provides road users with information about emergency and incident cases in the vicinity of a vehicle via the SR-MRN.
- Static (Dynamic) Route Guidance (S(D)RG) supports a driver with appropriate information about an optimal route to a destination

Three sets of equipment are defined to serve groups out of these RTI applications. The respective communication equipment is defined by a seven layer protocol stack, differing mainly in the first two layers. Layer three is common to all type of equipment and is based on RTI specific routing and addressing techniques.

Part of layer three and layers four to seven are proposed to use widely used standard protocols according to ISO/OSI.

Experiences gained from field trials and pilot projects are urgently needed to refine the operational requirements of the various RTI applications, currently under consideration.

Layers 1 and 2 depend on the performance required for a given set of applications. All three options of the proposed equipment combine communication with identification and relative positioning and cover short-range communication between vehicles and to the infrastructure:

In Option A of the equipment, packet-radio communication based on asynchronous multiple-access protocols for bursty traffic is supported. No protection against interference from hidden stations is provided and no maximum packet delay is guaranteed.

In Option B multiple-access with reservation is provided. Due to a slotted radio channel and introduction of slot reservation, continuous communication is supported, besides single packets. Stations must be locally synchronized with respect to the slot structure. Delay time for continuous mode communication is deterministic. However, no full protection against interference from hidden stations is provided.

Option C uses channel switched communication and techniques to nearly guarantee interference free channel establishment, despite hidden stations. To further reduce interference from hidden stations, subframes are used to assign communications capacity according to the direction in which a vehicle moves. Compared to options A or B, highly reliable radio channels are provided supporting, besides others, efficient use of radio bandwidth and real time applications.

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In Section 2 the basic idea of combining communication with identification and relative positioning is introduced. In Section 3 options A, B, and C are described in detail. Section 4 describes the layer 3 functionality. More details on the standard protocols recommended for layers 4 to 7 are found in section 5. A discussion of internetting functions and gateways to interconnect short- and long-range networks is presented in section 6. Section 7 contains the Integrated Communication Architecture of the COMBINE system for IRTE networks as proposed in this paper.

2. Communication and Relative Positioning

The three options of the COMBINE system have in common the ability to combine the functions of communication via a short-range radio network with, in addition, identification and relative positioning of the involved stations. If these additional functions are switched off, a normal communication equipment remains to serve RTI applications like S(D)RG, needing no relative positioning.

Transponder systems were claimed to be well suited for identification, relative positioning, and communication [1], [5]. Such systems apply multiple-access packet radio protocols like (S)-ALOHA, or CSMA to transmit a squitter signal in random time intervals containing a station's address, allowing other stations to interrogate and measure the propagation delay until a station's response. Such response is required to follow immediately an interrogation, using a separate frequency band.

We propose integration of the transponder function into the communication system. The system can then better be suited to communication, than is possible with the opposite approach, where the transponder is used for communication, too.

Instead of forcing an interrogated station to reply immediately, the reply is allowed to be transmitted after any suitable time delay, which length must be specified inside the response packet. This avoids operation of a separated frequency band, normally required with transponders for responses. We assume that a delay of some (non)integer multiple of a communication packet length is tolerable before responding to an interrogation.

Further we assume that both, interrogation and response, are part of normal communication packets. In Fig. 2.1 a slotted time axis is shown, presuming slot synchronous communication between adjacent stations. Such local synchronization was shown to be possible [14], but is not a prerequisite, since our proposal works also with asynchronous protocols. A sample of packet-radio communication between stations A and B is shown in Fig. 2-1, where packets are preceded by interrogation or response sequences, respectively, enabling the communication equipment to perform distance measurement.

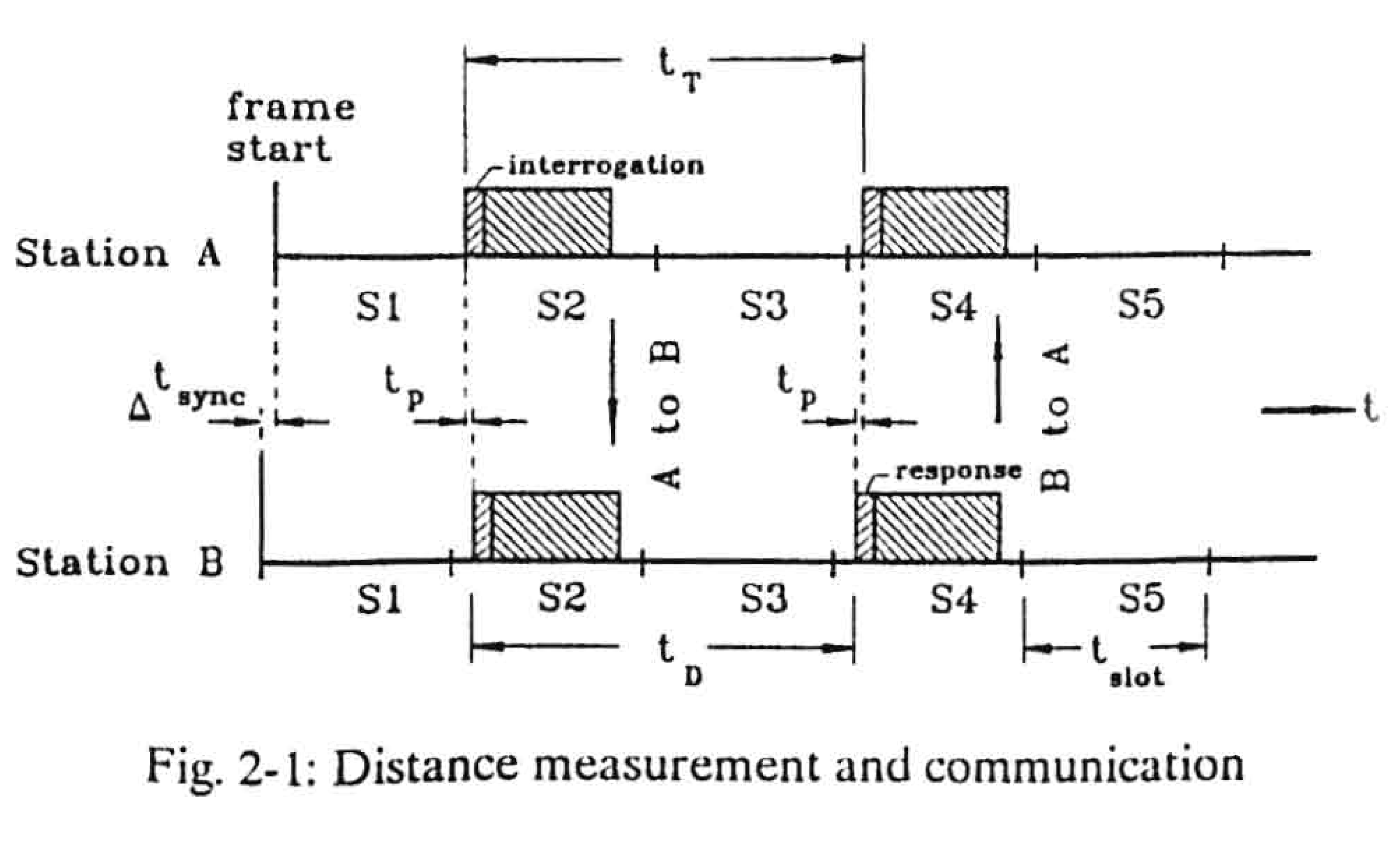

Fig. 2-1: Distance measurement and communication

Stations transmit hello packets in random time intervals, if they don't hear each other. A transmitting station A, communicating point-to-point to station B includes the interrogation sequence in its packet. The packet is received at B after the propagation delay t_p. Station B sends its next packet not at the beginning of its slot, but after a time delay t_D, which is communicated in the packet, and includes the response sequence as a prefix. A is then able to compute the round trip delay $2t_p$ and will transmit its measurement result to B as part of the next packet. To increase reliability of distance measurement, interrogation is periodically altered between the two stations. Distance measurement is performed as long as the communication relationship exists. Addresses used for communication uniquely identify which stations are involved in distance measurement. Apparently, such mechanism would also work without a slotted time basis. For an introductory phase where no integrated communication and distance measurement equipment is available, we propose to use separated equipment, where the transponder is synchronized by the communication equipment to transmit its interrogation and response sequences.

3. Options of the COMBINE Equipment

3.1. Option A: Asynchronous Multiple-Access

Option A is an early applicable system to serve communication, identification and localization, covering some demands of the RTI applications OD, ME, MRP, EW, SRG, DRG.

In the simplest version, the option contains only an asynchronously operating transponder system using two signals, one for interrogation and the other for reply purposes. If a station wants to know its distance from another station it transmits an interrogation. Any receiving station replies via a separate frequency band. The duration between interrogation and reply consists of the propagation delay and a fixed processing delay in the responding station. The only information exchanged is the distance between two stations.

In the normal version of option A we assume the transponder system being able in addition to offer comunication capacity [1]. Squitters are sent in random time intervals to identify a station to others through its address. Three signals are used: squitter, interrogation, and reply, each offering some capacity for information transfer. Addresses are used with these signals. The system covers distance measurement, identification and communication.

Media access is performed by use of a protocol like CSMA or pure-ALOHA. It is well known that the maximum throughput for such protocols, is much lower than for synchronous systems and that the delay until successful transmission of a packet is non-deterministic. Performance of pure-ALOHA is known to be very small. Analysis has proven CSMA to be a promising protocol, even in a hidden stations environment [2]. No real-time requirements can be served, however, which results in RTI applications IMC, ICC, and IIC not being covered by option A. Applications SRG and DRG can be served to some limited degree only.

3.2. Option B: Slotted Radio Channel

With Option B the COMBINE system applies a decentrally controlled slot synchronization mechanism [14], which allows synchronous operation of neighboured stations to support real-time applications through TDMA protocols. On that basis protocols like R-BTMA [13] are applicable. Common to these

protocols is that they are able to perform reservation of periodic slots, whereby channels can be provided.
Compared to option A, throughput is improved and delay is significantly reduced. Besides all of the applications covered by option A, in addition applications IMC, ICC and IIC needing real-time support can be served. However, the protocols used in option B are unreliable to some extent regarding interference-free access and handover of channels in time.

3.3. Option C: Channel Switched Communication

This option represents the most enhanced system for communication, identification and positioning, satisfying all known requirements like high reliability and real-time behavior from RTI applications OD, ME, IMC, ICC, IIC, MRP, EW, SRG, DRG.

Option C uses a frame and slot structure permitting to establish TDMA channels each carrying one packet per slot, which is known as the ISMA protocol [4]. Both packet and channel-switched communication is possible in parallel. To identify free channels in the short-range mobile radio network the DCAP (Decentral Channel Assignment Protocol) [15] and DMAR (Decentral Multiple Access with Reservation) protocols [3] were defined.

The DCAP protocol requires stations to continuously monitor all channels and to continuously transmit the information gained. A bitmap is used for transmitting the monitoring result, where one bit per channel indicates a channel's quality to be good or poor.

The DMAR protocol requires a station to transmit its observations on the quality of all channels, coded in two bit per channel, only when a station is forced through interference to handover from its used to another channel, or when a new channel is to be established. The communicating station(s) are then able to calculate all free channels being candidates for use to the interfered station in the channel reuse range and to establish one as a substitute for the interfered channel. DMAR is able to decentrally organize the smallest possible spatial channel reuse. No continuous transmission of a bitmap but accidental transmission of two bit per channel is needed. This feature of DMAR reduces the overhead of DCAP substantially, without reducing the functionality. Both protocols are comparable in their ability to operate in a hidden station environment.

Due to the capability of DCAP and DMAR to rapidly handover from an interfered to a free channel, option C is able to support highly reliable communication channels being well suited for real-time oriented applications. In comparision to option B, throughput, delay and channel economy are improved substantially. Reservation of channel capacity with respect to the direction, in which a station moves, is supported, which reduces the probability of channel interference by an order of magnitude, cf. [15].

Option C accomplishes the same applications as option B but with that performance, reliability and availability needed for all Co-operative Strategies in RTI-systems.

4. Mobile Radio Network (Layer 3) Protocols

The routing strategies described in this section allow communications with remote vehicles, traffic centers or data-bases. By multi-hop routing, the data packets are forwarded to their destination via other vehicles or roadside beacons acting as relays. Based on a basic concept [8], these routing algorithms are well suited for the complexity of large mobile networks with rapidly changing topology, for both vehicle-to-vehicle and vehicle-to-infrastructure communications. The following classes of communications are supported by the routing strategies described in this section:

- vehicle-to-vehicle (via other vehicles if required)
- vehicle-to-infrastructure via roadside beacons
- vehicle-to-infrastructure via vehicles and beacons
- vehicle-to-vehicle via infrastructure (if required)

For some RTI-applications a complete bypass of the Network Layer might be necessary.

For performance evaluation and protocol verification of recently developed communication protocols for media access (DCAP, DMAR, DAMAP, etc.; see Section 3) and routing (DOR, KOR, etc.), integrated simulation tools (SIMCO2 [10], [12], etc.) for simulation of vehicle-beacon and inter-vehicle communications, based on realistic mobility models and road traffic scenarios, have been developed. The results of extensive simulations currently being performed, are used for further refinement of the communication protocols and to specify optimal communication parameter values.

4.1. Short-Range Routing (SRR)

Each station (vehicle or beacon) broadcasts periodically information about direct (and indirect) neighbors (possibly transmitted piggy-backed with other data), thus providing the required information for 3-hop routing within the local area [8].

4.2. Direction-Oriented Routing (DOR)

Due to the mobility of vehicles, the network topology changes frequently, especially on two-way roads. Therefore, to support stable routes, direction-oriented routing algorithms have been developed, by which data packets are forwarded to their destination or to the next Fixed Routing Access Node (FRAN) preferably via vehicles moving in the same direction [8].

4.3. Knowledge-Based Routing (KOR)

For mobile communication networks with a rapidly changing topology, a new concept of a "Knowledge-Oriented Routing (KOR)" strategy has been developed [11], in which known vehicle characteristics and other important traffic information are taken into account, to forecast the future network topology, to avoid misrouted packets (caused by obsolete routing information). The key to this knowledge-based strategy is, that all stations within the zone of relevance maintain and update their knowledge-based cluster routing lists according to initial parameters, which were broadcasted by (new) stations. Therefore, explicit updates are necessary only, if the movement characteristics (speed, direction, etc.) of a station differs significally from its previous (broadcasted) intention (Position Deviation PD-Option). The amount of required updates can be reduced further, by taking known speed limits on specific road sections (Speed Limit SL-Option) and, in addition, the difference between the mean of the intended speed and the mean of the current speed of vehicles on a specific road section (Intended / Current Speed IC-Option) into account. Thus, with the detailed knowledge of the dynamic network and its expected topology, dynamic route changes according to the actual network topology can be performed without any time-lag, and the required routing updates are kept to a minimum.

5. Transport and Higher Layer Protocols

The characteristics of an integrated IRTE network made it necessary to develop specific protocols for the Physical, Data Link and Network Layer, as presented in Sections 2 to 4. However, for communications with remote hosts (data bases, etc.) on computer networks outside the integrated IRTE network (using network services like File Transfer, Electronic Mail, Virtual Terminal, etc.), standard protocols are required. Therefore it is reasonable, to use a standard protocol stack, for the higher layer protocols.

Not only for standard network services, but also for several RTI applications options of standard transport layer protocols (ISO/OSI TP0-4, etc.) can be used. However, for those RTI applications with a limited zone of relevance (short-range and local area) and high data/repetition rates (especially for cooperative driving applications), IRTE network specific transport and higher layer protocols with special performance might be required. The functionality of the transport layer includes also multiplexing as well as splitting and recombining features. For some RTI applications a complete bypass of the Tranport Layer might be necessary.

6. Internetting and Gateways to Other Networks

Several RTI-applications require communications with remote traffic surveillance and guidance stations, emergency centers (Red Cross, police, fire department), information and reservation systems (weather, time tables, hotel, flight, train), public services (busses, taxi) and databases on other public/private networks. These RTI-applications will be supported by providing internetting:

- via an IRTE specific infrastructure network, where available,
- by integration of the GSM mobile celluar network, using traffic channels for data communications with remote hosts, if required,
- by integration of other available communication links (RDS, Paging, Satellite, etc.),
- via other public/private networks (X.25, ISDN, etc.).

An example of such internetting scenarios are shown in Figure 6-1 below.

A standard Internet Protocol (ISO/OSI-IP) with an IRTE specific addressing scheme is used to provide the required interconnection with other public/private networks.

If both hosts (source and destination) use the same application protocols, then other public/private networks (GSM, X.25, etc.), can be used as transit networks, thus avoiding unnecessary protocol conversion in IRTE gateways to these networks. Therefore, the proposed Integrated Communication Architecture (see Section 7 below), including standard protocols, would have significant advantages over one, using protocols for some of the higher layers with a similar, but incompatible functionality. Only real-time requirements of some RTI-applications and an untolerable protocol overhead would justify this protocol conversion, with the additional disadvantage, that all data packets belonging to the same communication session, would have to travel via such a higher layer gateway.

Specific gateway algorithms (PDN Cluster Addressing, Hierarchical VAN-Gateway algorithms, etc.) have already been specified to support internetting between IRTE hosts via the system of X.25 Public Data Networks (PDN), as well as worldwide access to remote data bases on the PDN (see [6] and [7]).

7. SR-MRN Integrated Communication Architecture

The complete communication protocol stack of the COMBINE system has been described in Sections 2 to 6 above. Depending on the RTI application related to the areas of operational interest, the communication requirements (currently being defined according to a proposed specification structure [9]) will vary between a short-range/local and a wide-range/global zone of relevance, high data rates versus low rates, short/long lifetime, high/low priority, etc. In addition to the RTI applications, also standard network services like electronic mail (X.400/SMTP), file transfer (FTAM/FTP), virtual terminal (VT/TELNET), for access to remote databases, etc. will be required.

To support this wide variety of requirements, the following PROMETHEUS Protocol Stack, including several options is used in the COMBINE system (Figure 7-1):

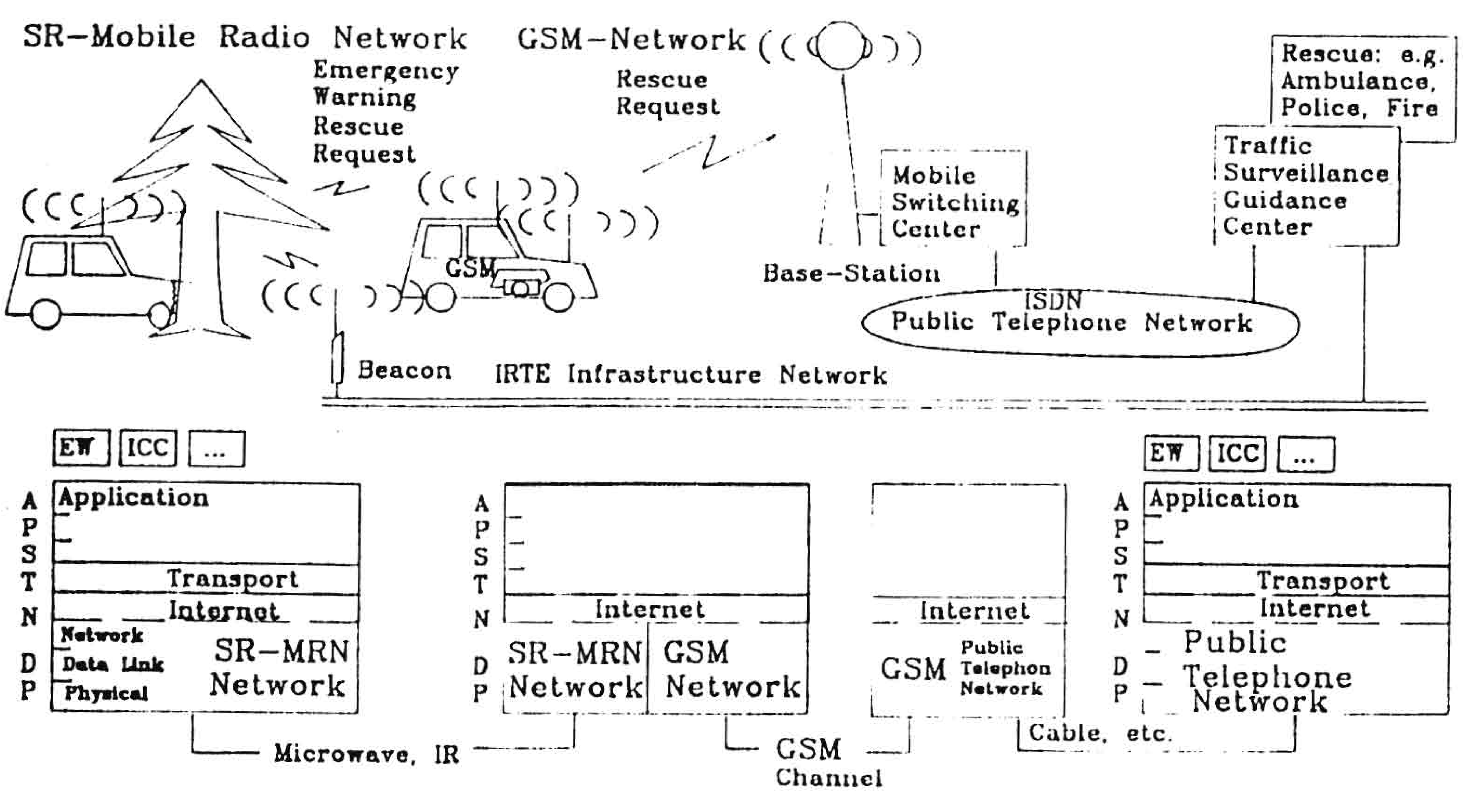

Figure 6-1: SR-MRN Integration: Emergency Call via GSM

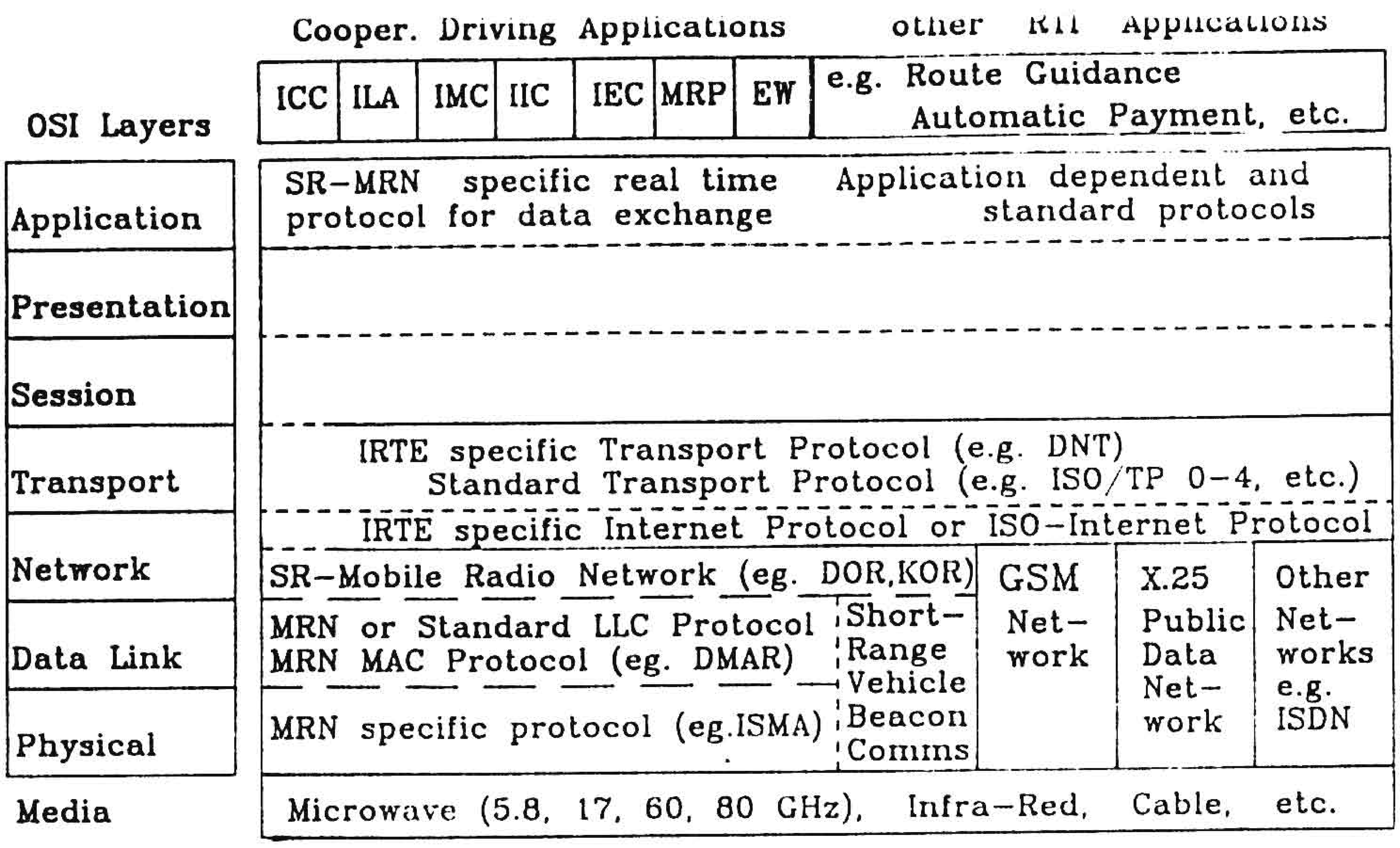

Figure 7-1 SR-MRN Integrated Communication Architecture

8. Conclusions

In this paper, COMBINE, a modular system combining communication, identification and relative positioning for vehicle-to-vehicle and vehicle-to-infrastructure communication in an IRTE network, has been presented. The ability of the COMBINE system to configure the equipment properly to serve just those RTI applications being of importance to some user group proves to be highly cost efficient. The functionality of the recently developed communication protocols for the physical layer, the data link layer and the network layer of the short-range mobile radio network has been discussed. The higher layer protocols are mainly based on widely used standard protocols (ISO/OSI) and cover any services known for computer communication networks. Internetting and gateway protocols support the interconnection between the IRTE network and other public/private networks (e.g. GSM, X.25 Public Data Network, ISDN, etc.). Therefore, the proposed COMBINE system, which is based on an integrated communication architecture of IRTE network specific and standard protocols, satisfies the demands of any communication related RTI application supporting driver information and therefore traffic safety and efficiency.

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