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DMAR

A Decentral Multiple Access protocol with Reservation

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Abstract: Recently defined PROMETHEUS FUNCTIONS need a high capacity short-range mobile radio network to satisfy the functions' demands for inter-vehicle and some vehicle-to-infrastructure communication. As vehicles are mobile and their receive range is very limited, specifically adapted Media Access Control protocols are required. DMAR is a further development of the DCAP protocol proposal which is able to provide reliable radio channels with very low protocol overhead and a controlled handover of channels in case of interference.

1. Introduction

Due to the current uncertainties w. r. t. the freceney band to be used for a future PROMETHEUS short range radio network and the resulting channel characteristics, the PRO-COM interest group Media Access Control Protocols has developed a number of protocol proposals, cf. /MaRü88/, /ADGZ89/, /DBLS89/, /HeWa89/, /KRHW89/, /MaCo89/, /TaGo89.1/, /TaGo89.2/. These proposals, together, cover a wide area of assumptions on the network architecture and the radio transmission system, but taken in isolation, each is characterized not only by promises but also some draw-backs, dependent on the applications considered.

The DMAR protocol, introduced in this paper, is based on our previous work /HeWa89/, /RKHW89/, where a synchronous TDMA-structure is considered, where each communicating vehicle at least operates one of a large number of TDM-channels.

Such system satisfies two of the most important requirements defined for the PROMETHEUS FUNCTIONS F10 (Intelligent Manoeuvring and Control), F11 (Intelligent Cruise Control), F12 (Intelligent Intersection Control) and F14 (Emergency Warning) namely, reliable, continuous data exchange and is able to operate under real-time constraints. It is further known that such applications require precise and actual data describing the relative position of any transmitter received with in some scenario dependent receive range. To serve the functions satisfactorily channel access should neither disturb nor interfere any other existing communication relationship. Interference is possible by hidden stations, since a short-range radio network is only partly meshed, cf. Fig.1.

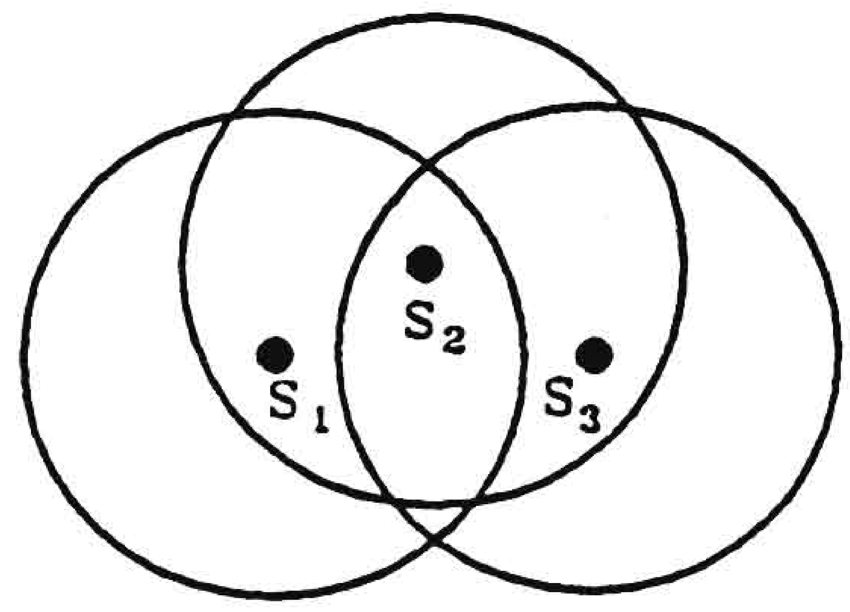

Fig. 1: The hidden station problem

In Fig. 1 station S3 is hidden to station S1. Without support from station S2, station S1 is not able to know what channel is used by station S3. Therefore, if station S1 accesses the transmits on a channel being already used by station S3 to communicate to S2, station S1 is an interfering transmitter to S2. The problem becomes more sophisticated for mobile stations, in that the network topology and thereby the number of hidden stations is continously changing then.
To overcome the hidden station problem, previous protocol proposals introduced a bitmap to distribute channel occupancy information with 1bit per channel as part of each used slot. Then the communication activities of hidden stations become visible. A drawback, however, is the excessive overhead resulting from transmitting the bitmap.

The provide full status information about all channels used in the interference range of a potential transmitter and to avoid the continous transmission of a bitmap, we developed the MAC protocol DMAR (Decentral Multiple Access protocol with Reservation).

2. Mobility

The impact of mobility on the design of MAC protocols was analytically analysed in /ZhWa89/ and /ZhHeWa89/. There, vehicles are considered moving, either in one direction (UniDirectional Mobility, UDM) or in two opposite directions (Bi-Directional Mobility, BDM). Handover of an used channel to another one is assumed necessary, whenever radio connnectivity has changed due to mobility such that undue interference is produced to any receiver. The main result of this studies is shown by the following graph:

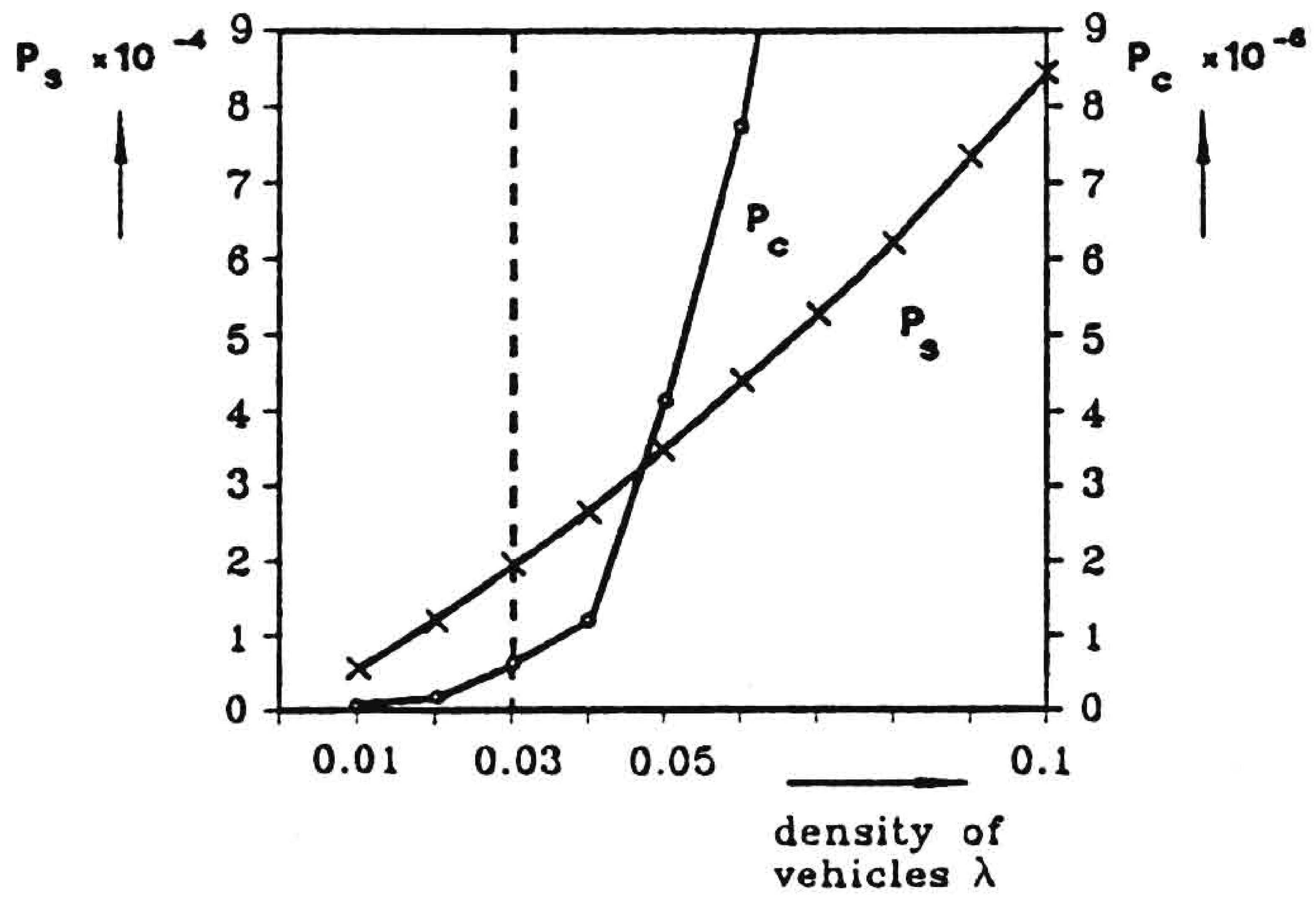

Fig. 2: Channel handover and channel collision probability

denotes the vehicle density. The broken line indicates a mean density of 3 vehicles per 100m, which corresponds to a throughput of 3600 vehicles per hour, a relatively high load for a highway scenario. The speed of vehicles is assumed to be normally distributed with mean 120km/h and standard deviation 19.2km/h. The probability, that no vehicle enters the receive range of a vehicle in this scenario during a time interval of 0.1sec is more than 0.98, cf. /HeWa89/, considering the UDM. The left hand ordinate shows the probability for a handover from an used to another channel to be one per 5000 frames (one per 500sec). The right hand ordinate shows the probability for a channel conflict in case of a handover to be neglectably small. In case of the BDM these probabilities become more than an order of magnitude worse. One consequence is that, especially for the UDM, handover is a very low probability event. Therefore it is not justifiable - at least for this scenario - to transmit channel state information in each slot. First results of studies for downtown scenarios indicate that the handover rate is significant smaller, due to the reduced relative mobility of vehicles.

3. The physical channel

The radio channel is known to be unreliable compared to hard wired transmission media, due to multipath propagation and interference. Two important properties of the channel and their impacts on the Media Access Control (MAC) Protocol are briefly discussed.

3.1 Multi-Path Fading

Different radio propagation paths between a transmitter and a receiver, cause different propagation delay, phase and energy of the same signal. Dependent on a receiver's location, the receive signal strength is subject to deep fades, whilst the fade duration varies dependent on the relative mobility between transmitter and receiver, e.g. at 60 GHz, a relative mobility of 100 km/h and a data rate of 1 Mbit/s, a fade lasts approximately for 18 μs, /Lu90/. This phenomena called multi-path fading, might destroy packets which are up to 200 us in length, according to the acrrent PRO-COM working assumptions. It is worth noting, that fades in slots of consecutive frames (50 ms/frame) are completely independent. Obviously observation of a fade, which results in a burst of bit errors is not sufficient to conclude that a handover to another (better) channal is required.

3.2 Co-Channel Interference

Co-channel interference results from re-use of a channel at distant location. It is known, that the signal energy at a given location, although too small for being successfully demodulated and decoded, represents a high interference potential to the signal of a transceiver transmitting simultaneously and being closer located to the receiver. The ratio interference range to receive range required to meet a small given BER is frequency dependent and was calculated to be appr. 1.75 at 60 GHz, cf. /Lu90/. MAC protocols in hidden-station environments must take interference into account and try to avoid assignment of channels being co-channel interfered.
A channel which packets a receiver will never be able to receive with a predefined quality due to strong interference although the transmitter is in its receive range, is termed to be collided. A channel being currently interference free, might loose single packets due to fades.
It remains to the MAC protocol to distinguish this two cases and to reassign channels only in case of co-channel interference.

3.3 Coding and Exchanging of monitored Channel Quality

The effectiveness of MAC protocols in a hidden station environment heavily depends on the actuality and detail of information available to a receiving station. Most important is knowledge about the transmit quality observed with channels, currently in use. We assume that a training sequence as part of each slot is used by the transmission system to support a dynamic adaptation of the receiver to the actual channel parameters. Such technique is in use e.g. with the CEPT/GSM cellular radio system [Lange,88]. The training sequence might be used by DMAR to decide, whether a slot is used or not, which is possible with high probability for signals received from transmitter more distant, than the receive range. It appears to be possible to detect all transmitters in the interference range of a receiver by evaluating the result of the demodulated training sequence. Taking PRO-COM working assumptions on quality monitoring into account, cf. /HeMAC89/, DMAR uses the following criteria:
Q1. Mean received signal power.
Q2. Signal to noise ratio.
Q3. Bit Error Rate (BER): (estimated by evaluating known bitpattern e.g. of the training sequ.). In addition FEC codes may be used.

We assume vehicles to be equipped to be able to decode any used channel. By use of the quality indicators defined information characterizing the Quality Status (QS) of each channel is proposed to be coded such that in each station at least the following information is avaible:

4. The DMAR protocol

As mentioned in chapter 2, probability of the need for channel handover per slot very low, especially if direction decoupled assignment of slots is applied by the ISMA protocol, cf. /HeWa89/. The channel request rate of a station depends on how often a service is used that needs a channel to one, some or, all neighboured vehicles and how often a channel selected requires handover per frame due to interference. The QS information is transmitted with DMAR **only** if it is actually needed, that is in cases **only** where

(i) a received channel is observed to degrade unduely in quality
(ii) a new channel is required to access a service.

Thanks to the rare occurence of such events the excessive overhead resulting from continuous transmission of 1bit per channel via the bitmap as in the class of CSAP2 protocols /RKHW89/ is reduced to be well below 1%. An exact analysis is subject of our current studies.
Two questions are to decide on, to provide the DMAR protocol with relevant information.
(iii) Which channels are in use in one hop plus interference range around a station ?
(iv) Has a missed packet in one receive channel been interfered temporarily or collided ?

Question (iii) is anwered on demand issued by any station needing such information through reception of QS-information from the relevant stations and (iv) is solved by applying a well designed handover algorithm.

4.1 DMAR: Gathering complete QS-information

Each time cases (i) or (ii) occur, a free channel must be determined.
In case (ii) station, say S, transmits a status report request packet either in a channel station S is already using, in a channel being observed free in the one-hop range or, in the S-ALOHA section of the ISMA protocol. The Dest-Address Field 0 is defined as "ALL". Any addressed station, receiving such request transmits its observed QS-information in a status report response I packet using its own channel. Each station observing such reply **and** having not sent such reply itself, transmits a status report response II packet. The purpose of this sequential response procedure is to ensure, that station S gets the complete answer to question (iii) after at least three frames.
In case (i) a station S' observing decreasing receive quality of the channel used by station S, informs S by transmitting a handover request packet addressed to S. If the interfered channel is used for a point-to-point connection, station S has already the complete answer to question (iii) and the information gathering procedure is completed. If the interfeed channel is point-to-multipoint (broadcast), station S then performs the procedure of case (ii) but using a status report request II packet, which in turn is immediately answered by status report response II reducing the overhead from three to two frames.

A: no received signal energy above a predefined threshold is detected (Q1).

B: training sequence is detectable with some predefined probability, but demodulation is not possible.

C: demodulation and decoding is possible, but with unsufficient according to quality Q2 and Q3.

D: demodulation and decoding possible with high quality according to Q2 and Q3.

It is assumed, that the MAC protocol can access and take advantage of knowledge of

E: the distance to a transceiver using channel number x.

0 0	A
0 1	B
1 0	C
1 1	D

Table1: Quality Status (QS) coding

Table 1 codes the QS information. QS is exchanged between stations under the control of the DMAR protocol. For that purpose the packet formats in Fig. 3a) and 3b) are defined. The use of the Destination-Address field is explained in the next chapter where the DMAR protocol procedures are described in detail.

type	Dest. Address	QS-info	training sequ.	QS-info

Fig.3a: Packet format of DMAR: control packets

The following packet types are defined:

001	status report request
010	handover request
011	status report request II
110	status report response I
111	status report response II

Table 2: Types of packets

All other packets use the normal packet format coded by type 000, cf. Fig. 3b :

000	data	training sequ.	data

Fig. 3b: Normal data packets

Note that in most cases only normal data packets will be exchanged. The static protocol overhead is reduced to the type indicator(3 bit).

4.2 DMAR: Determination of free channels

After issuing a status report request packet at least three frames later station S has the complete answer to question (iii) and is able to determine free channels in the real channel reuse range. Calculation of channels termed to be free comprises three decision modes (normal, priorized, emergency) realizing reliable transmission of a packet according to the priority of the packet and the instantaneous communication load situation:

Procedure 4.2.1 (Normal Mode): In normal mode the two bit characterizing a channel's status according to table 1 are combined by applying a logical OR function. A consequence is, that all channels where signal power is detectable, are excluded for a channel assignment.
The resulting bitpatterns of all stations having transmitted their QS information are then combined by applying once again a logical OR function over each bitposition of all bitpatterns, cf. CSAP2 class protocols in /KRHW89/. Each channel corresponding to a bitposition being '0' after this algorithm represents a free channel in the one hop plus interference range environment. One of such channels is selected at random to be used.
In case procedure 4.2.1 does not produce at least one free channel (or a predefined minimum number of channels), procedure 4.2.2 is applied if a priorized channel is demanded. Procedure 4.2.3 is reserved only for emergancy calls.

Procedure 4.2.2 (priorized mode): In priorized mode only the first bit of the QS information, cf. table 1, is used to determine channels as free or used. The further determination of free channels follows procedure 4.2.1. This procedure results in channels, where signal power is decodable, to be termed as free. Because of the capture effect at least receivers in the close vicinity are reachable reliably.

Procedure 4.2.3 (emergency mode): In emergency mode, when procedures 4.2.1 and 4.2.2 result in no free channels all channels except channels with QS = D are considered as candidates for use, according to procedure 4.2.1.

Such three modes allow a controlled overload of the system by relying on the near-far effect (capture) during high system load, realizing a lower blocking probalility to priorized and emergency messages, even in overload situations.

4.3 DMAR: Channel handover algorithm

Each station locally keeps book of each channel's status. If a receive channel used by station S decreases in quality, which is assumed to be the case when a channel in two consecutive frames is termed in its quality as AA, AB, BA or BB the station S transmitting on that channel is addressed and asked to handover its channel by a 'handover request' transmitted by station S via its own channel.

A station S' receiving a 'handover request' performs procedure 4.1(i). If the asking station observes in the next frame a 'status report request II' packet transmitted by S' the handover procedure is acknowledged and going to be executed. Otherwise the asking station retransmits the 'handover request' up to three times. If S' doesn't transmit a 'status report request II' packet up to then, the station S is not received at S' and has to change itself its channel using procedures 4.1 and 4.2 to avoid a potential deadlock situation.
A special situation is, that a station observes no other station in its receive range. To avoid the deadlock situation mentioned (which is a very low probability event) such a station also changes its channel after some random time interval.

5. Summary

DMAR, although designed to handle connectionless broadcast communication, is able also to handle point-to-point and point-to-multipoint communication (broadcast), thereby satisfying all requirements contained in the service specifications, cf. /KrRo89/.
The protocol is a further development of CSAP2, cf./KRHW89/, especially DCAP. DMAR produces a very low static protocol overhead when applied to short-range mobile radio networks, where relative mobility of vehicles is limited as is known for all PROMETHEUS scenarios, especially if a direction of movement oriented assignment of slots in a frame is used, as proposed by the ISMA protocol. Reliable channels for continuous communication are ensured by provision of QS-information about all channels in the real reuse range allowing or immediate decentrally controlled handover when needed. The ability of load dependent evaluation of priorized channel status permits controlled system overloading by priorized and emergency messages without sacrifying reliability of channels in use. Moreover, DMAR recognizes short fades and doesn't over-react with a handover request, unless the fade rate becomes too high. Alltogether the handover rate is minimized significantly, thereby improving reliability and throughput of channels used.

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