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HIGHLY RELIABLE CHANNELS FOR SHORT-RANGE MOBILE RADIO NETWORKS

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ABSTRACT

A number of future road traffic services, like controlled overtaking and driving in a file, will require very reliable radio communication channels. To serve this specific requirement, a combination of two new ideas is proposed to define a short range multi-services radio network. We assume a very limited transmission range of a station's radio equipment of below 1km, which advantageously supports a spatial reuse of radio channels. Time is assumed to be divided into frames and frames into slots. Slots can be used either for single-packet transmissions or to form TDM-channels. The high relative mobility of stations (vehicles) is expected to result in a severe danger of unintentional signal interference between co-channels, which at time of their establishment have been interference free, due to the spatial distance of the locations of their use. Our first idea is to reduce the effect of station's mobility by defining trunks of radio channels being allocated according to the direction in which stations are moving. What remains as a source for possible radio interference is the relative mobility of stations, moving into the same direction, which obviously is much smaller than that of all vehicles together. This proposal is worked out to some detail using simulative and analytic mobility models and is expected to result in highly reliable radio channels to be used for real-time oriented continuous communications. Our second idea aims at taking into account both, the propagation and attenuation conditions of radio waves, and the need for a completely decentralized access control protocol to the radio channels. We propose a new channel-access control protocol, which enables mobiles to locally calculate those channels being unused and interference free in the local environment and therefore being free for access.

KEY WORDS: Multiple Access, Hidden Stations, Capacity Assignment, Mobile Radio, Packet Radio, Short Range Communication.

1 Introduction

We designed the Integrated Services capacity MAnagement (ISMA) protocol for a short-range radio network following three basic requirements, namely

A) assessment of the various communication characteristics of services requiring short-range communication (comms.),
B) consideration of what performance is available from today's transmission equipment,
C) minimization of the transmitter/receiver equipment cost by integrating all short-range services into one common network using either 40 to 60 GHz radio or IR for transmission.

Task A leads to voluminous research work which is not the subject of our paper. However, we had to agree upon some working assumptions about the services expected, which form the basis for a classification of comms. types and their characteristics.

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2 Reference Scenarios

A number of research groups within the European research programme PROMETHEUS have developed reference scenarios, from which appropriate comms. requirements were derived, e.g. [PTF,1990],[Kemeny and Meulemeester,1990], [Thomas et al, 1987], [Sandstroem, 1988]. Thereby, a number of potential applications and related services, yielding candidates for an integrated short-range radio network, were defined.

They can be classified into at least four types. The first type of service is characterized by its priority requirements. Here services related to an emergency warning system (EWS) can be accomodated. EWS messages arise, for example, as consequences of accidents. Priority is secured by reserving a fixed portion of the available capacity exclusively for this purpose. We call this type "EMERGENCY COMMUNICATION".

The second type of service is characterized by its demand for connection oriented comms, which we call "CONTINUOUS COMMUNICATION". One important representative is the so-called "PROXIMITY COMMUNICATION" for cars driving harmonized interms of speed and relative distances in a single lane, which is a first candidate for experimental verification by the automotive industry. The main task is to manage the basic organizational control of such files. Assuming existence of a car internal relative location and distance control facility, the resulting comms. requirements are:

- power control with transmission range up to 500m,
- unlimited number of participating vehicles,
- pure information capacity needed per car is 20byte every 0.1s,
- connectionless broadcast of datagramm messages,
- channels have to be highly reliable.

Other applications of this type are: controlled merging on highways and controlled overtaking. It is worth noting, that such services require very reliable comms. channels.

Concerning vehicle-to-roadside comms. exchange of comparable sized rates and volumes of information has to be performed between the vehicle and roadside facilities, e.g. with a traffic light at a crossing, in order to exercise cooperative strategies. This type of comms. is called "SELECTIVE COMMUNICATION" and some additional requirements are:

- 50 vehicles are communicating simultaneously at maximum,
- channel capacity must be at least 500 bit/s.
- acknowledged message transfer may be required.

The third type of service is called short-range packet radio comms. and is mainly characterized by its demand for single-packet, non-periodic transmissions. We call this type "BURSTY COMMUNICATION". Applications are for example inter-vehicle signalling, broadcast of warning messages, road conditions, etc. Management functions, such as connectivity update, to obtain an instantaneous view of the local network connectivity also are of this type. Concerning vehicle-to-roadside comms, services like distribution of the status of a traffic light, or beacon-to-vehicle location update can be identified, which happen periodically with repitition rates of a few seconds. To ensure, that there is enough time left for reliable reception of the complete message, the transmission range must be adaptively controlled according to the speed of the vehicles. Other applications may require connectionless information exchange between mobiles and beacons. The requirements of the third type can be summarized as follows:

- BURSTY COMMUNICATION
- no acknowledgement needed
- adaptive transmission range from 10m-200m
- up to 20 vehicles transmitting simultaneously
- individual update rates
- short delays
- 25 byte information volume per event.

The fourth type of service is characterized by its occasional demand for a high speed channel of approximately 100 kbit/s to be used from the beacon to the vehicle, for example to update an onboard digital road map. The cumulative requirements for an integrated short-range radio network are as follows:

- both, continuous and bursty traffic, with acknowledgement, must be handled, efficiently,
- priorized communication must be possible
- the transmission range must be adaptive,
- at most 60 vehicles must be able to perform selective comms. simultaneously,
- the information volume per single message comprises at most 25byte,
- the update rate needed is 0.1s,
- maximum channel capacity must be 2 kbit/s,
- a road-to-vehicle high speed channel is required.

3 Media Access Control Protocol

Due to the limitations of transmission radii of stations, not all of them are in their respective receive radii. A number of well-known media access control protocol exist, according to different applications, medias, technologies, etc. Taking the mobility of vehicles and their large expected number into account, all protocols using fixed or deterministic access are not applicable.

Contention protocols like ALOHA and S-ALOHA are best suited for packet radio networks having nearly unlimited mobility, so that forecast about the expected number of receivers being in a stations receive range after some given time interval is impossible. Therefore, such protocols are applicable only for services requiring small small transmit capacities (e.g. one packet) in nonperiodical intervals.

CSMA protocols suffer like ALOHA protocols from the hidden terminal problem, which poses some unreliability on packet transmissions. Moreover, continuous comms, requiring availability of small but constant transmission capacity over some limited time period, is not feasable, using such protocols. Receiver initiated busy tone techniques are not applicable because of the broadcast character of a significant portion of the communications traffic.

So what remain then applicable are protocols applying an implicit or explicit slot reservation using TDMA techniques. They fullfil the requirements for real-time and reliable continuous communication and appear to be well suited for applications with a limited mobility of stations, as is the case here.

[Mann and Rueckert,1988] proposed a concurrent slot assignment protocol (CSAP), which tries to organize a decentral channel access using implicit reservation according to the R-ALOHA protocol [Lam,1980]. Assume a TDMA system using a frame and N slots per frame. According to that protocol each station listens continuously to any slot in a frame and creates the so-called 'observed information', which is a bitmap of width N, containing all slots marked '1' where a message from any one-hop distant station was received correctly within the last frame. All other slots are marked '0'. This information is distributed by each station being active in communication, once per frame as part of its slot. By bitwise OR-ing the received with the observed information each receiving station is able to calculate the so called 'local information', telling it, whether a slot (channel) is occupied or free in the two hop environment.

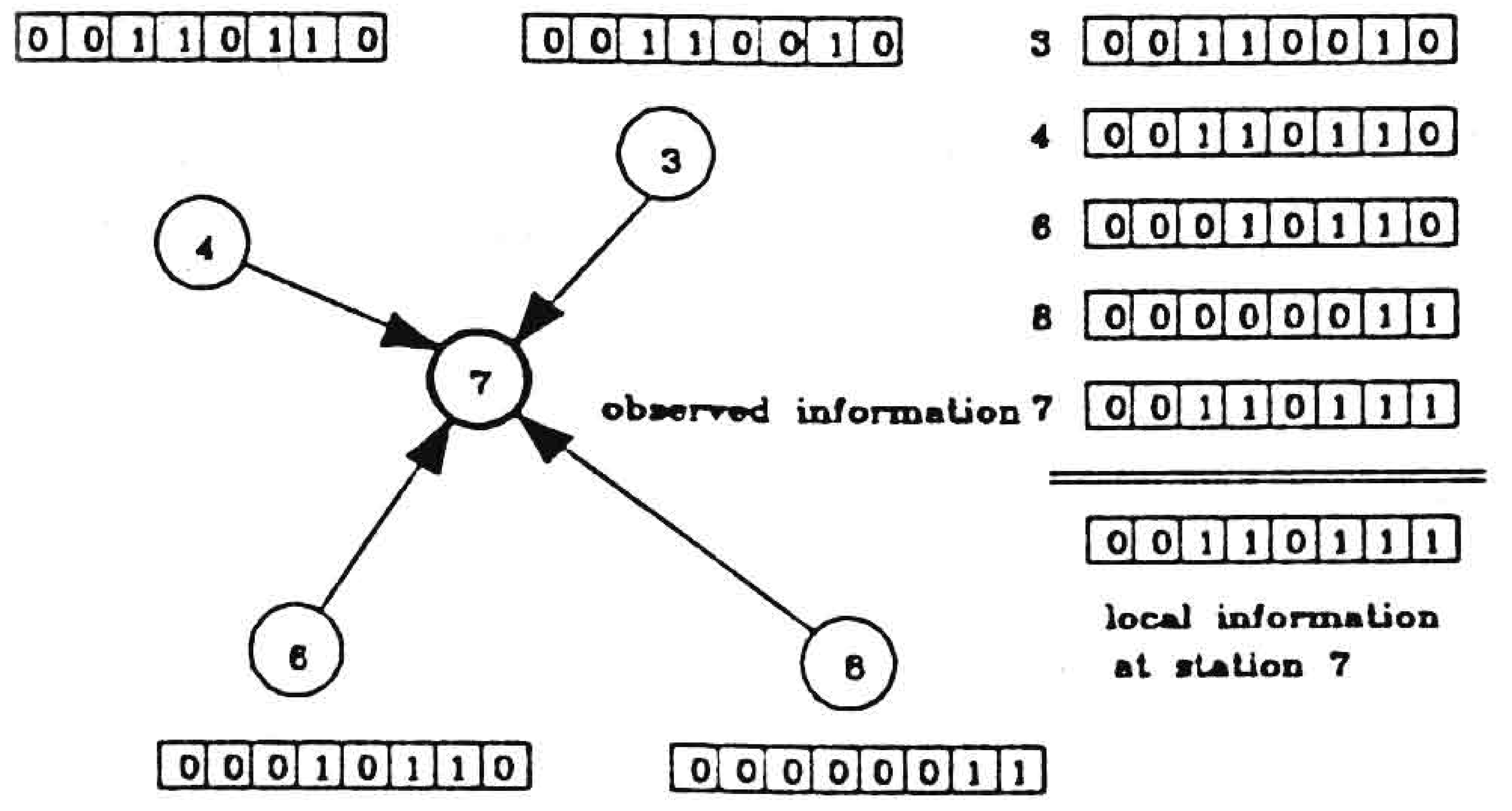

Fig. 1: Calculation of local information of station 7 using slot 7, cf. [Mann and Rueckert,1988]

Considering physical and applicational facts, a modification of CSAP is necessary to make it operational in the real world. Due to the propagation attenuation of radio waves, in the short-range radio network not all pairs of vehicles will always be within their respective receive (rx) ranges. Instead of this a partly meshed network results, which roughly spoken has essentially an one-dimensional topology, reflecting the connectivity of all cars moving into the same direction, cf. figure 2. There, the rx radius R of the stations defines, what stations are neighboured to each other (one hop distant) and what are not. Due to the ISMA protocol (cf. section 6), no radio interference exists between subnets A and B or A and C.

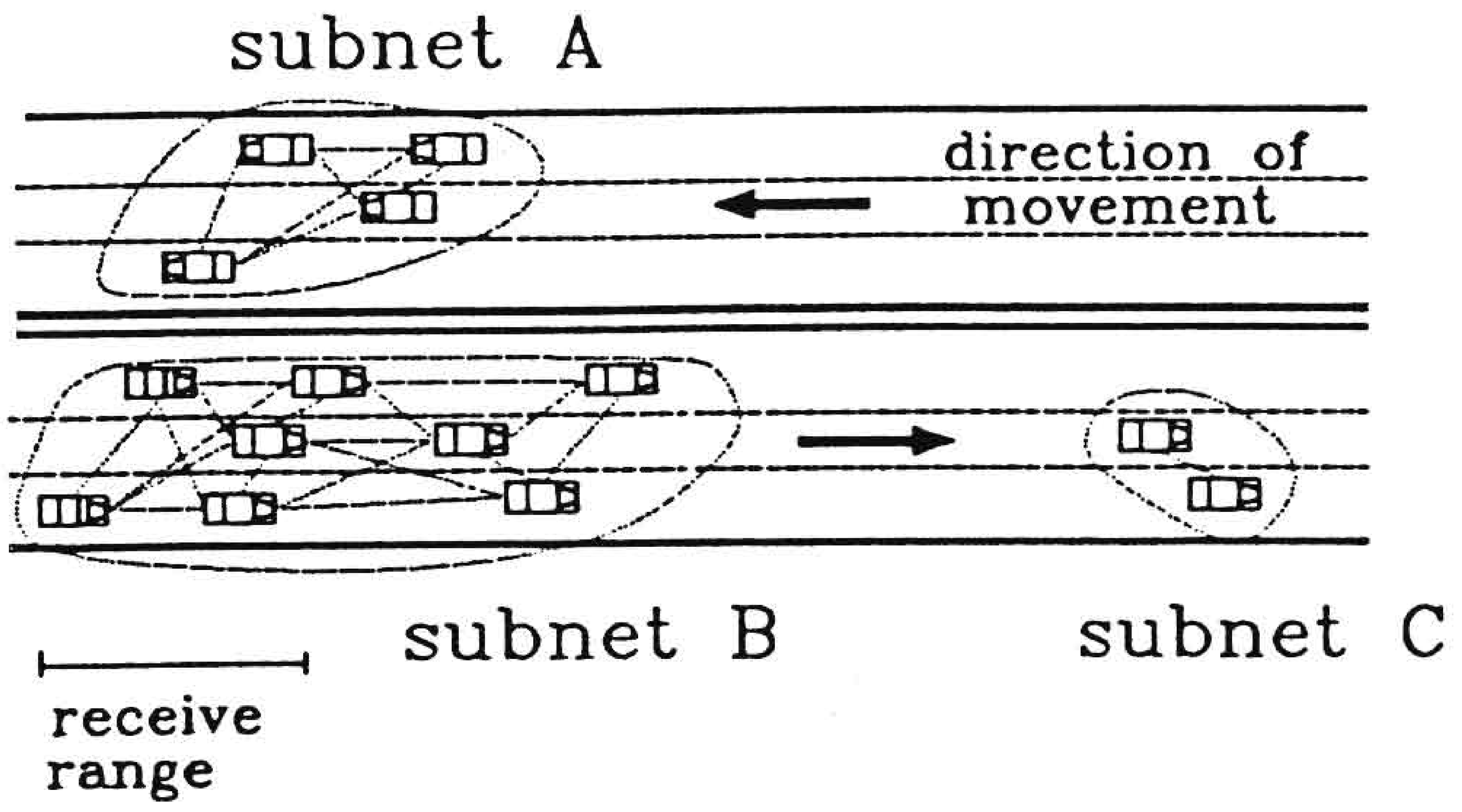

Fig. 2: Example of a three-lane highway. R is the maximum distance allowed for direct comms. between neighbored stations.

Unfortunately, a distance greater than R between two stations does not guarantee, that they are free to occupy a channel, being locally detected free. In figure 3, a situation is depicted, where a transmitter S communicates with a receiver E, where R is the maximum rx range to sustain a predefined bit error rate (BER). This comms. possibly is interfered, if station E simultaneously receives a signal from station I.

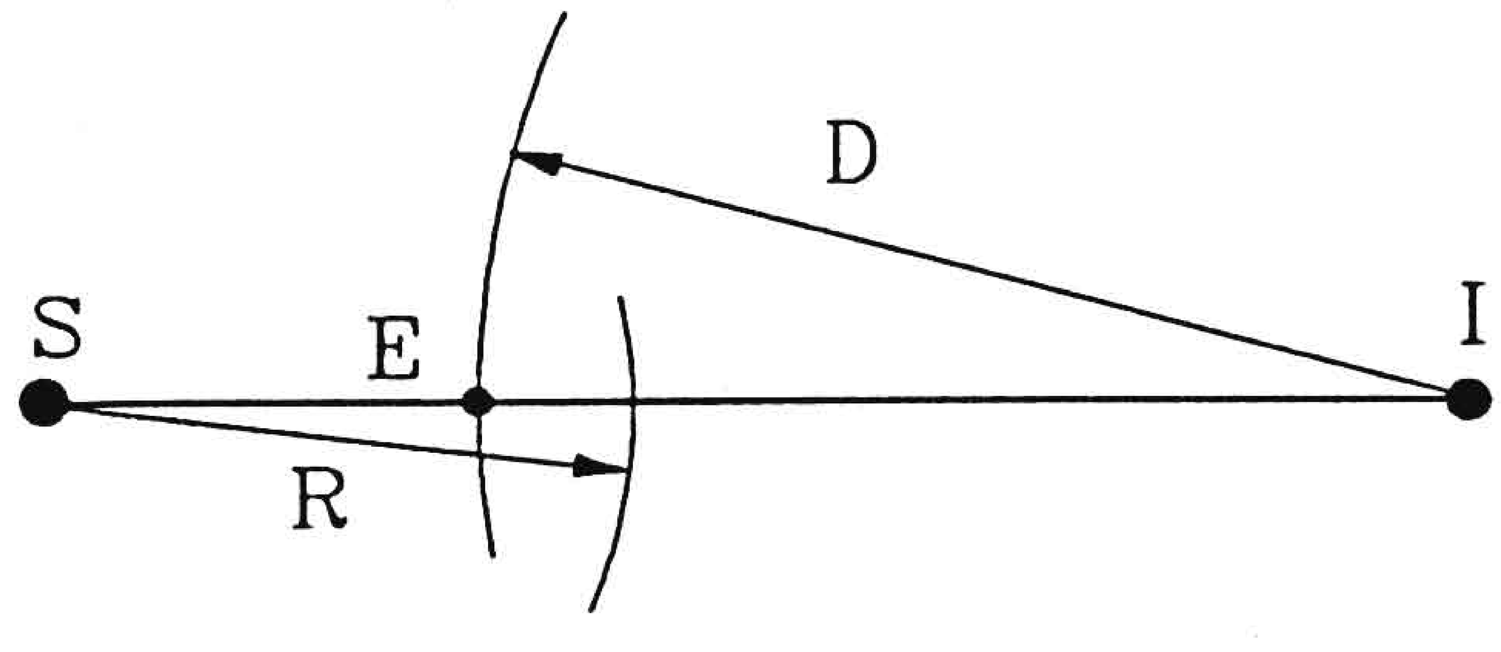

Fig. 3: Interference of stations I and S at receiver E. R is the maximum rx range of E to sustain a predefined BER.

Generally, the signal-to-noise ratio Ps/Po of a receiver is affected adversely, if interference is present. The signal strength of a radio signal is proportional to 1/(R*R), where R is the distance between transmitter and receiver [Lee,1986]. Signals transmitted simultaneously from different transmitters add up at the receiver and reduce the signal-to-noise ratio. It is known that a transmission is successful only, if the distance of any interfering transmitter I from a receiver E is at least D=n*R. From radio applications it is known, that n should be at least 3. For some radio frequencies, the propagation attenuation is substantially increased, resulting in a reduced value for n, e.g. at 60GHz n=2 is believed to be sufficient. In the present application, stations must decentrally be able to decide, whether a channel is free for transmission or not. This requires knowledge about the status (free/used) of all channels within a radius of (D + R) around any station. This requirement, however, is not taken into account by the CSAP. There, instead of a radius 3*R, a range of two hops (which is less than 2*R) around each station is covered. Another drawback of CSAP is worth mentioning: Assume k channels to be secured, the capacity needed by CSAP is k*k bit/frame. If a frame duration is e.g. 100ms and carries 500 channels/frame, CSAP requires a protocol capacity of 2.5Mbit/s which is unacceptably high. In section 7 we propose a further development of CSAP which we call Decentral Channel Assignment Protocol DCAP. In conjunction with the ISMA-protocol (defined in sections 6) DCAP appears to be very promising to meet all the requirements mentioned.

4 Performance of Millimeter Wave Equipment

The following performance characteristics of today's available transmission equipment are very close to the requirements of the application considered, and serve as an example. The parameters are derived from an experimental implementation currently under development:

- max. receive range is about 150m with pan cake diagram. Using fan beam antennas, with horizontal and vertical beamwidths of about 30 degrees, receive range up to 1000m is possible,
- bit error rate BER below 1.0 E-4,
- channel availability due to perticipation is 99%,
- total transmission capacity is about 2.5 Mbit/s.

5 The Proposed TDMA-Frame

Considering the above mentioned requirements and technical facilities a TDMA-structure according to fig.4 seems to be suitable. Time is divided into frames and frames into slots. Although we assume global frame synchronization we believe that only neighboured vehicles must be synchronized correctly, whereby a slide of the frame would be tolerable the greater the more distant vehicles are. A frame length of 100ms containing 500 slots, each with a duration of 200μs is proposed. A slot contains a 40μs guard gap to protect against propagation delays and synchronization errors. Subsequently, 400bit follow, about 100 of which are needed for receiver synchronization, packet-header, and error detection/ correction purposes. In case slots are used channel switched, 100bit of the remaining 300bit per slot are assumed to carry access protocol related data as described in section 7.

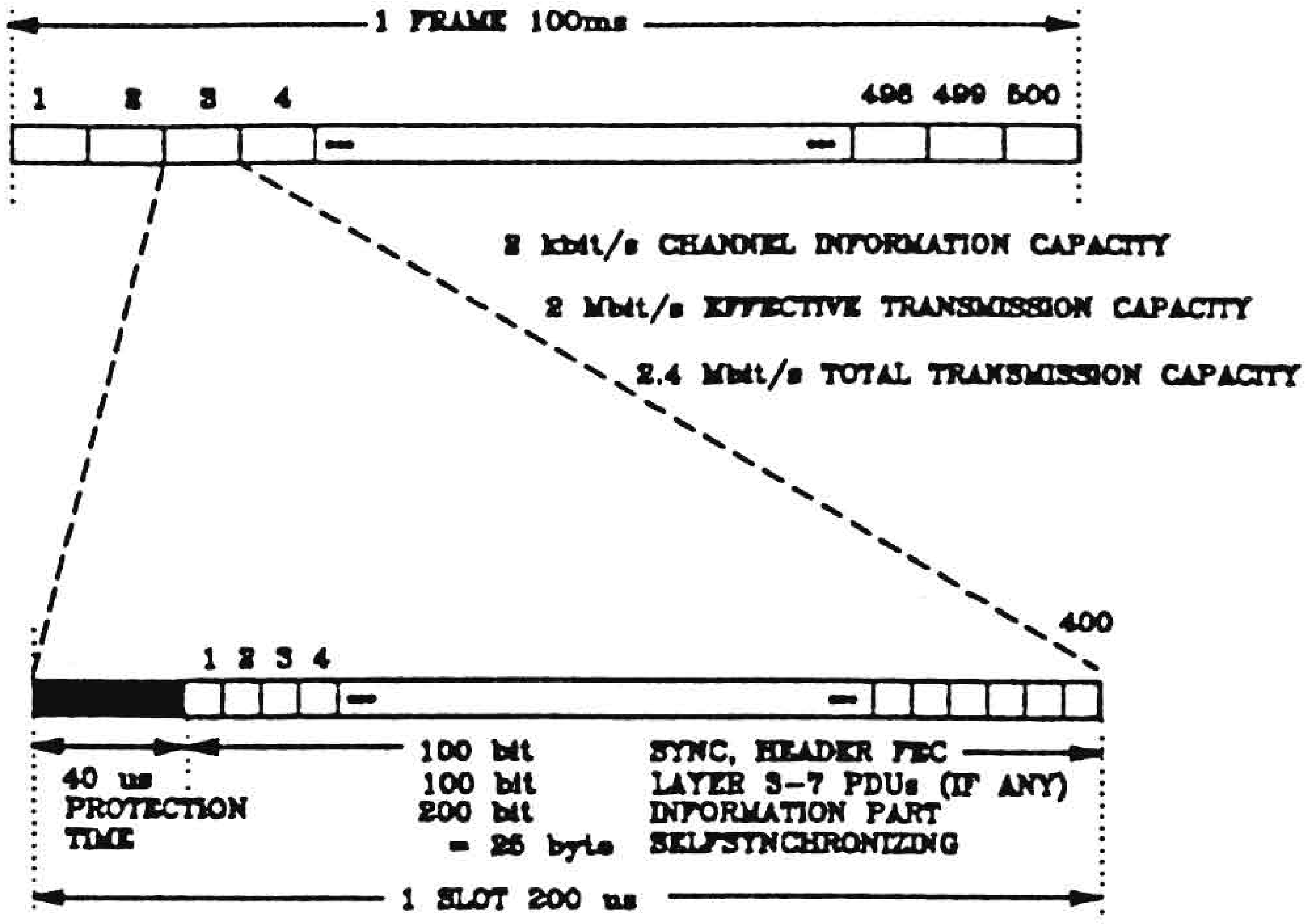

Fig. 4: The proposed TDMA structure

200bit of the slot carry pure information, which is sufficient to serve the applications' needs. If we use a slot periodically consecutive frames we get a channel information capacity of 2kbit/s. The overall information transmission capacity is appoximately 1.5Mbit/s, the effective capacity, including the bits required for protocol related data, is 2Mbit/s and the total capacity is about 2.4Mbit/s.

6 The ISMA Protocol

The ISMA protocol assigns channel capacity based on direction of movement and slots to concurrent services. The proposed slot assignment to comms. types results from identifying service demands having similar communication needs and from allocating to each a seperate section of the frame. These sections are called subframes. The absolute figures given for numbers of slots/channels, capacity etc. are based on the current working assumptions for the system and might change through further development.

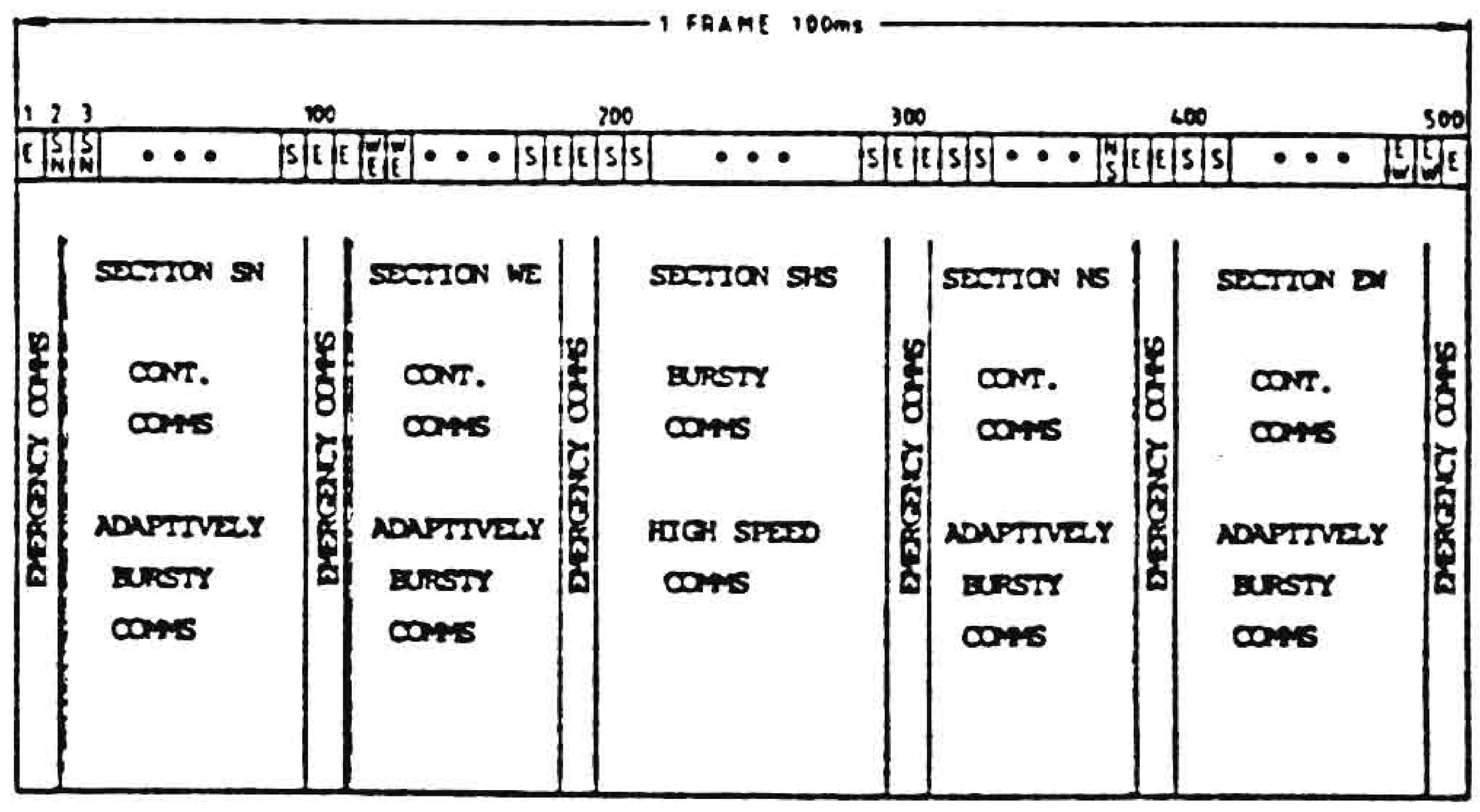

Fig. 5: Static slot assignment by the ISMA-protocol

Emergency related communication takes place in one (distributed) subframe containing slots depicted with E. These slots are controlled by a media access control (MAC) protocol called DCAP (cf. section 7) and are well distributed over the entire frame to guarantee nearly collision free access after a maximum delay of 20ms.

Vehicles asking for continuous comms. are assigned to one out of four subframes, each comprising approximately 100 channels. Thereby, four trunks result, being reserved for vehicles moving into one of four (logical) directions: south-to-north (SN), west-to-east (WE), north-to-south (NS) and east-to-west (EW). Using this allocation of frame capacity it is guaranteed, that radio interference of vehicles moving into different directions is completely impossible. Moreover, relative mobility of vehicles moving into the same direction which might cause interference, is substantially reduced, according to the relative small differences in speed of such vehicles, compared to vehicles moving opposite.

If a channel is requested but not currently available in the respective subframe, a channel borrowing mechanism from other subframes might help to serve the demand. Definition of the borrowing function is out of the scope of this paper, see [Hellmich,1989]. Whenever a vehicle changes its direction of movement, say from SN to EW, it has to handover its used channel from subframe SN to EW, cf. fig. 5. We call such change a channel subframe handover to distinguish it from the case, where a channel handover takes place within the same subframe, due to degraded quality. A subframe handover is a consequence of the ISMA protocol definition and would otherwise not be necessary. Since a handover reduces channel reliability and throughput, because it could result in a channel conflict during the reassignment phase, an accumulation of subframe handovers must be prevented. Such handovers are to be expected just at such critical locations like intersections, merging lanes, junctions, etc., where the highest possible reliability must reached. To combine the advantages gained by the ISMA protocol with these requirements, a hystereses function for subframe handover was defined in [Hellmich,1989].

Assignment of transmit capacity on a subframe basis through the ISMA protocol does not restrict collection of channel occupancy information, cf. section 7, to the own subframe. Instead of that, stations also receive slots of the other subframes and keep track of the channel occupancy there. Such information is needed when the direction of movement is going to be changed, which requires a handover to the respective subframe.

The subframe containing slots 200 to 300 is designed to serve bursty comms. demands of all vehicles by offering random access slots for packet radio applications. These slots are used e.g. to broadcast local status information of vehicles and do provide a 100kbit/s one-way high-speed channel by defining some 33 consecutive slots within this subframe as one TDM-channel. The system can provide a maximum number of three such channels in parallel, or, if required, one 300kbit/s channel. Most of the slots of the four direction oriented subframes, in addition, are available for bursty comms under the control of the ISMA-protocol.

The structure of the messages used is shown in Fig. 6. The channel oriented subframes use the format (A) whilst format (B) is used in the packet radio part.

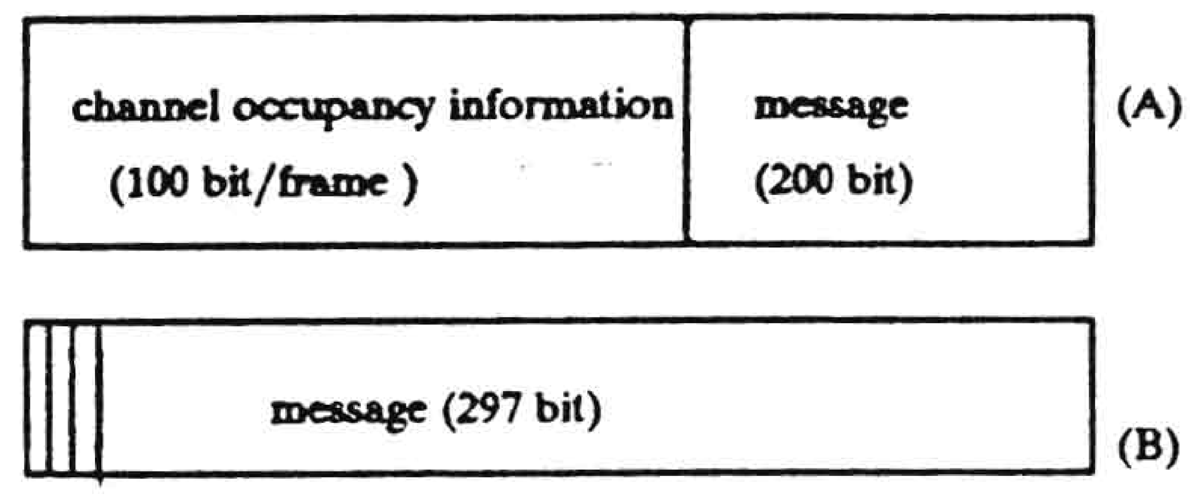

Fig. 6: Structure of messages transmitted in (A) the channel and (B) the packet switched subframes

7 Decentral Channel Assignment Protocol DCAP

The goal of capacity management is to assign overall channel capacity to the different services in a totally decentralized way, according to the different requirements, in order to obtain a cost effective integrated short-range radio network. To achieve this goal, it is a promising approach to gather all locally available information on the current quality status of any channels to support a decentrally controlled channel access protocol. To serve applications needing reliable continuous communications, the channel access control protocol should assign, in case of a handover or a demand for a new channel only a channel, which neither disturbs nor interferes any other ongoing communication relationship.

We state, that it is impossible for only one MAC protocol to handle all requirements mentioned satisfactorily, because they differ too much. Consequently, our approach defines six parameters to support management of the MAC layer, namely (A) received-signal strength, (B) bit error rate observed, (C) trunk occupancy, (D) relative distance, (E) direction of moving and (F) type of service. MAC management comprises the tasks of allocating a slot/channel out of the total available frame capacity to a service demand and assigning the appropriate MAC protocol. Allocation and assignment depend on the following information being available locally at each station:

A) Received-signal strength: The receiver is assumed to be able to detect the signal-to-noise ratio in each slot. We distinguish three possible states: The received signal strength is

(i) above a given margin, e.g. 10dB above channel noise, resulting in a sufficiently high signal strength to receive with a predetermined low BER.

(ii) between x dB and 10 dB, which appears when the transmitter is too far distant or one or more messages are transmitted simultaneously, but decoding is impossible or results in an unacceptably high BER. The signal level is too high, however, to assume the channel being not used.

(iii) below x dB, indicating, that the slot is free for use.

B) Bit Error Rate: Stations are assumed to be able to calculate the actual BER performance by evaluating the synchronization sequence or some FEC code used.

C) Trunk occupancy: Each station transmitting in a subframe XX (XX=SN,WE,NS,EW) continously observes local channel occupancy of its frame XX as follows: A bit-map, containing one bit per channel of the trunk, is set according to the received signal strength to '1' in cases A(i) or A(ii). Otherwise (case A(iii)) the bit is set to '0'. After performing an OR-operation on all received bit-maps the occupancy of the subframe in the one-hop plus interference range environment is available, reflecting the local occupancy information of the respective station, cf. Fig. 1. The bit-map of slots in subframe SHS only contains three bit, (cf. Fig. 6), each indicating one of the three high speed channels as used ('1') or free ('0'). A high speed channel is used, if in 33 consecutive slots of subframe SHS cases A(i) or A(ii) were detected.

(D) Relative distance: Each station is assumed to know the distances to its neighboured stations, from which it receives.

E) Direction: Each station is assumed to know its logical direction of moving.

F) Service-Type: Each station decides itself, which service it is going to use and which of the respective slots is chosen for access.

A) to D) are sources of information to DCAP and are used to access slots/channels and perform handovers (HO) when necessary. E) and F) support the MAC management performed by the ISMA protocol.

DCAP HANDOVER PROCEDURE:

If quality of a channel received degrades, which is detected from decreasing signal-to-noise ratio and/or decreasing BER, the station transmits via its own channel a "Handover Request (HOR)" addressed to the respective transmitter. If the HOR is received by the transmitter, it selects a free channel and switches over to that. Otherwise the requesting station repeats its HOR up to three times. If the transmitter addressed does not change its channel nevertheless, the station itself performs a HO. Selection of a new channel is a random choice out of the free channels marked ('0') in the local occupancy information.

DEEP FADING RESISTENCE:

DCAP keeps book of each channel in use on a frame basis and tolerates one missing packet without initiating a HO.

Multi-path fading at 60GHz is known to disturb significant parts of a whole slot, cf. [DACAR,1989], and to result in no correlation of slots of consecutive frames.

Collisions under DCAP are possible only during phases, where two or more stations collide at a common receiver after deciding to establish a new connection to it, or after a handover from a bad to a free slot, which is a low probability event, cf. chap. 8.

A special situation occurs, when no other station appears to be in the receive range of a station. Then, the station has to handover its channel after some random time interval, to avoid a permanent collision possible with a station transmitting in the same channel.

It is worth noting, that DCAP was formally specified in ESTELLE and validated by simulation, cf. [Hellmich and Walke,1990b].

Summarizing, the advantages of the protocol DCAP are:

- independence of attenuation of the frequency used
- high reactivity to topographical influences supporting fading and interference conditions and from wheather conditions,
- high reliability of the channels provided, thanks to both, the ISMA protocol and the ability to be equipped and able to instantaneously handover to a free channel, whenever the current channel suffers from bad quality
- complete and save decentral control
- capability to cope with adaptive tx/rx power

The combination of A) to E) leads to management strategies, which benefit into high overall system performance. Especially DCAPs ability to cope with adaptive tx/rx power is expected to substantially improve the capacity utilization and throughput performance of the proposed system, cf. [Gotthardt and Perz,1989].

The overhead for transmitting the trunk occupancy bit-maps, is reduced to a quarter of the amount necessary with the CSAP. Apparently, it is easy to reduce this overhead further, e.g. by a factor of two by introducing eight instead of four directions of movements and a subframe would comprise then 50 slots. In addition the bit-map might be transmitted multiplexed per channel using a number of frames.

8 Modelling of Mobility and performance of ISMA and DCAP

Performance evaluation of both protocols ISMA and DCAP does require modelling of mobility. We used an analytical and a simulative mobility model. The analytical model assumes stations to be randomly distributed on an unlimited line leading to a Poisson distribution for the number of stations in a given line segment. Stations are either assumed to all have the same direction of movement, which is called uni-directional mobility (UDM), or one half of them move in the opposite direction named bi-directional mobility (BDM). Stations are assumed, further, to each have an individual speed, being normally distributed. The model is used to derive the probabilities p_i (i=0,1,2,...) that exactly i stations enter the receive range R of a given station S during a time interval Δt. These probabilities depend on the distribution and the density of stations, their speed distribution and the length of the time interval Δt. For further details, cf.[Zhu and Walke,1989].

The simulative model represents vehicular traffic as realistic as possible, by taking into account empirical extracted values for vehicle densities and speed distributions measured on German highways, cf. [Heidemann and Hotop,1984]. Movement of vehicles is modelled correlated and driver actions are classified into two categories, one for sportsmanlike and the second for defensive drivers. The simulator estimates the probabilities p_i by counting the appropriate events.

In both models the parameter λ represents the mean number of stations per line unit.

8.1 Modelling DCAP

Our investigations focus on the need of handover (HO) performance of DCAP especially under the capacity management of the ISMA protocol. Modelling is restricted to the case, that a station S must change its channel, due to co-channel interference from other stations resulting from mobility. We make the following assumptions on the communication system:

A1) Every station has exactly one channel all the time it is active.

A2) Every station has always a packet to transmit in its channel.

A3) No overload situation occurs, i.e. there is always a free channel available for HO.

A1) and A2) are close to the actual working assumptions for the applications mentioned, cf. [PTF,1990],[Kemeny and Meulemeester,1990]. A3) simplifies analysis. We do not consider the cases a) that the system might be overloaded and b) that during HO a collision might occur. It has been shown [Hellmich et al,1990], that for the above given parameter settings a) and b) are very low probability events.

The physical channel is assumed to be ideal, if stations are in their respective receive ranges. By DCAPs ability to tolerate single packet damage caused by multi-path fading, the probability of an HO not forced by co-channel interference is well below 0.0001, cf. [DACAR,1989]. We further assume

A4) The probability, that during the time interval Δt two or more stations enter the reuse range ((D+R)*2) of a station S, is zero, and the probability, that exactly one station enters the reuse range of S is $(1-p_0)$.

Looking at fig. 7 we see, that the error made by A4) - for our application - even in case of an unrealistic high density of stations is well below 0.05% for the UDM and below 2.3% for the BDM.

After having calculated and simulated the probabilities p_i (i=0,1,2,...) we easily can derive the probability, that a station S has to change its channel p_{HO} to be

p_{HO} = P { station S' has the same channel as station S | station S' enters the reuse range of station S }

The probability, that station S' enters the reuse range of station S is simply $(1-p_0)$, cf. A4), and the probability, that S' has the same channel as S depends on the density λ of stations, the number K of communication channels available, the receive range R and the interference range D. Even in the worst case when stations S and S' are R+D apart from each other, they both know by provision of the DCAP the channels used or interfered locally. Consequently, S' has the same channel as station S with probability $1/(K-\lambda(D+R))$. The probability for a HO of station S, therefore, is

$$p_{HO} = 1/(K-\lambda(R+D)) * (1-p_0)$$

Throughout the following calculations K is set to K=100, the receive range R is set to R=100m (R=150m) and therfore, with n=2, we get D=n*R=200m (300m). Stations are assumed to have normally distributed speeds with mean 120 km/h and a standard deviation of 19.2 km/h. Moreover the time interval Δt is set to Δt = 0.1sec, which is the frame length.

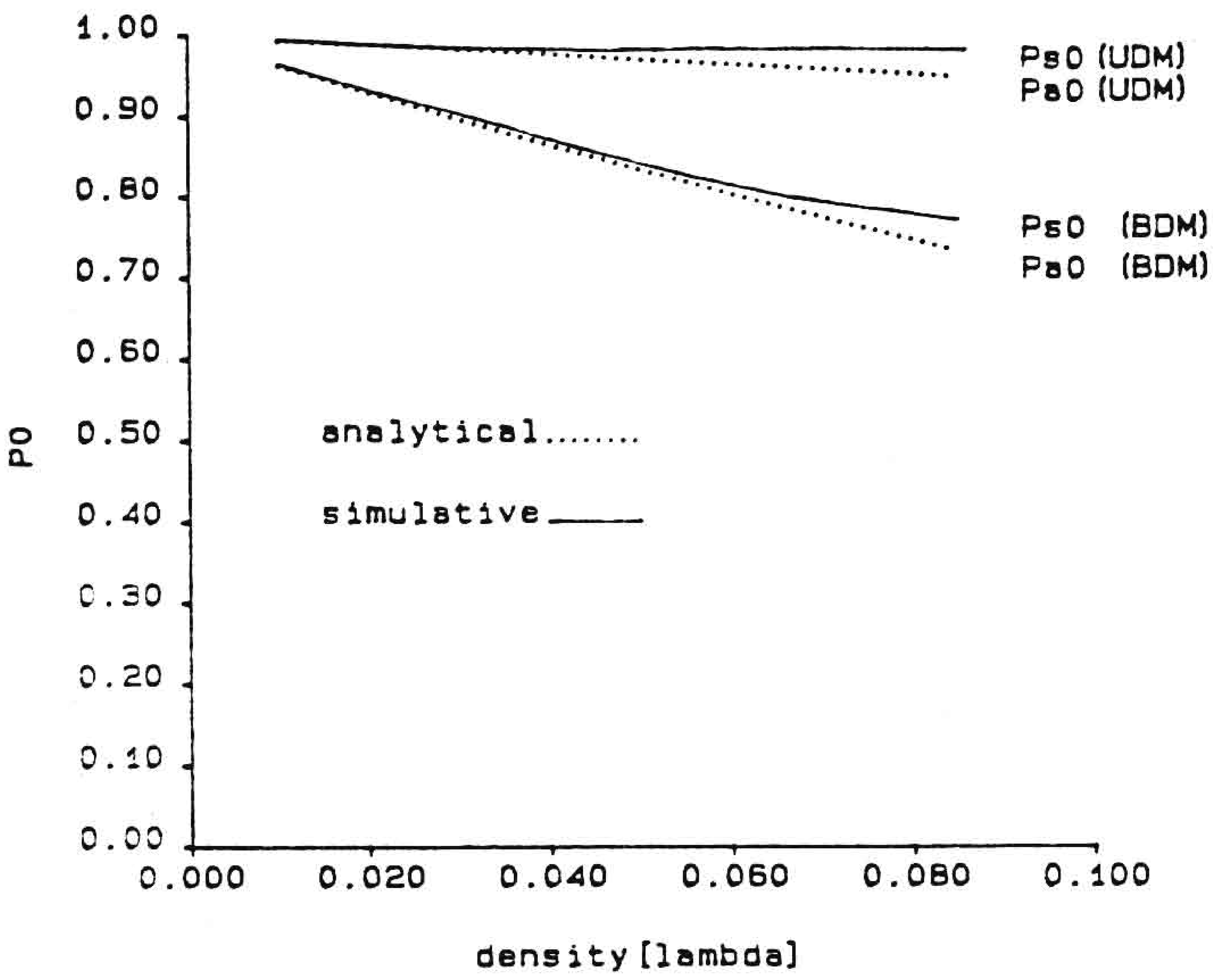

Fig. 7: No station enters the reuse range of a station (for UDM,BDM)

Figure 7 shows the probability, that during Δt the radio connectivity doesn't change. Obviously these probabilities are smaller for the BDM than for the UDM, whereby the difference becomes greater the higher the density is. Especially for the UDM we can observe an increasing gap between the analytical and the simulative results. A density of λ = 0.03 is eqivalent to three vehicles per 100m.

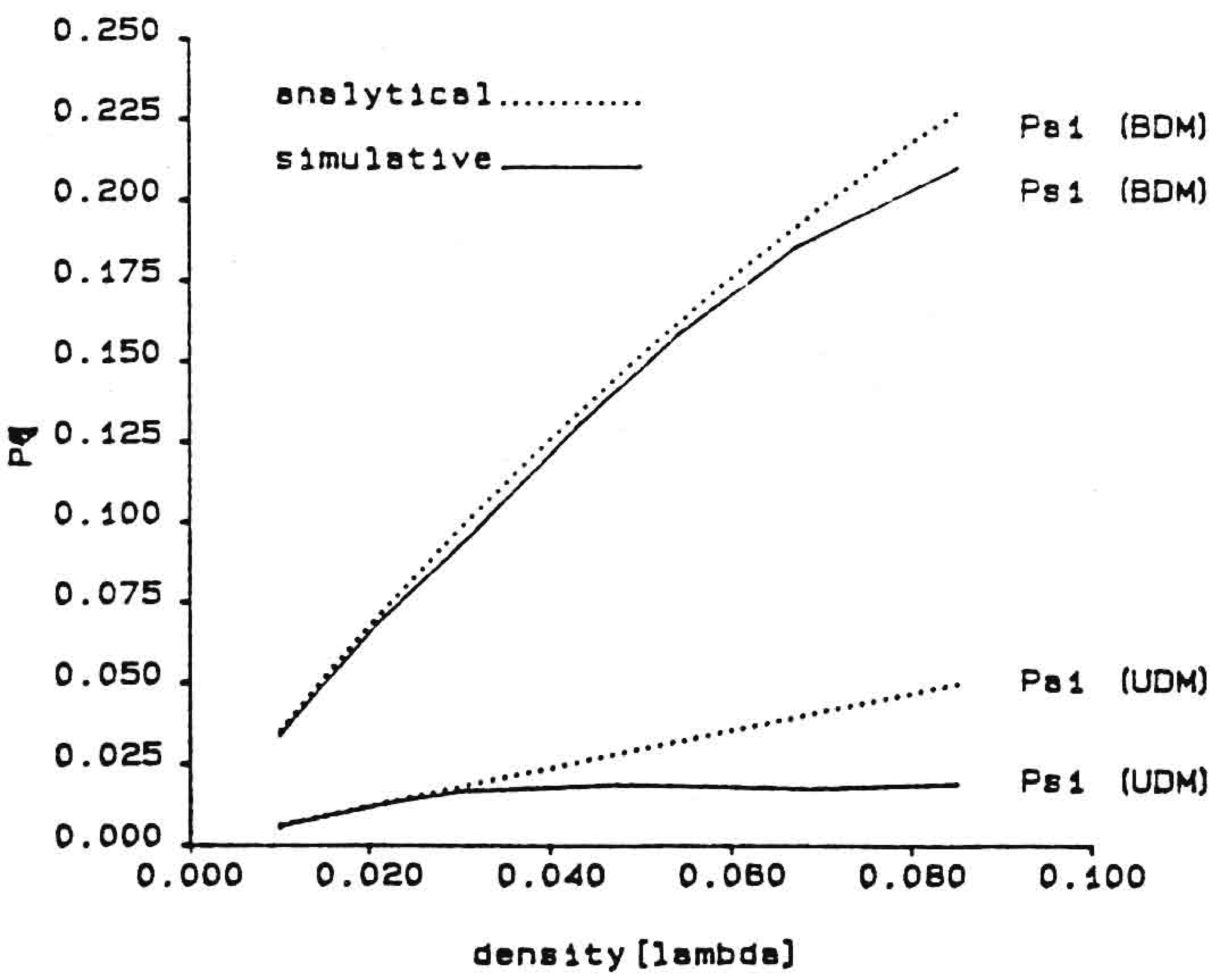

Fig. 8: One or more stations enter the reuse range of a station (UDM,BDM)

The increasing gap within the curves for UDM could better be observed by looking at the probabilities for the UDM in fig. 8. The reason is, that with increasing density of stations an increasing number cannot move freely, but have to adapt their speeds to slower moving stations, as overtaking becomes more and more impossible. This effect results in decreasing relative mobility, which is utilized by DCAP under control of ISMA by direction-oriented assignment of communication capacity.

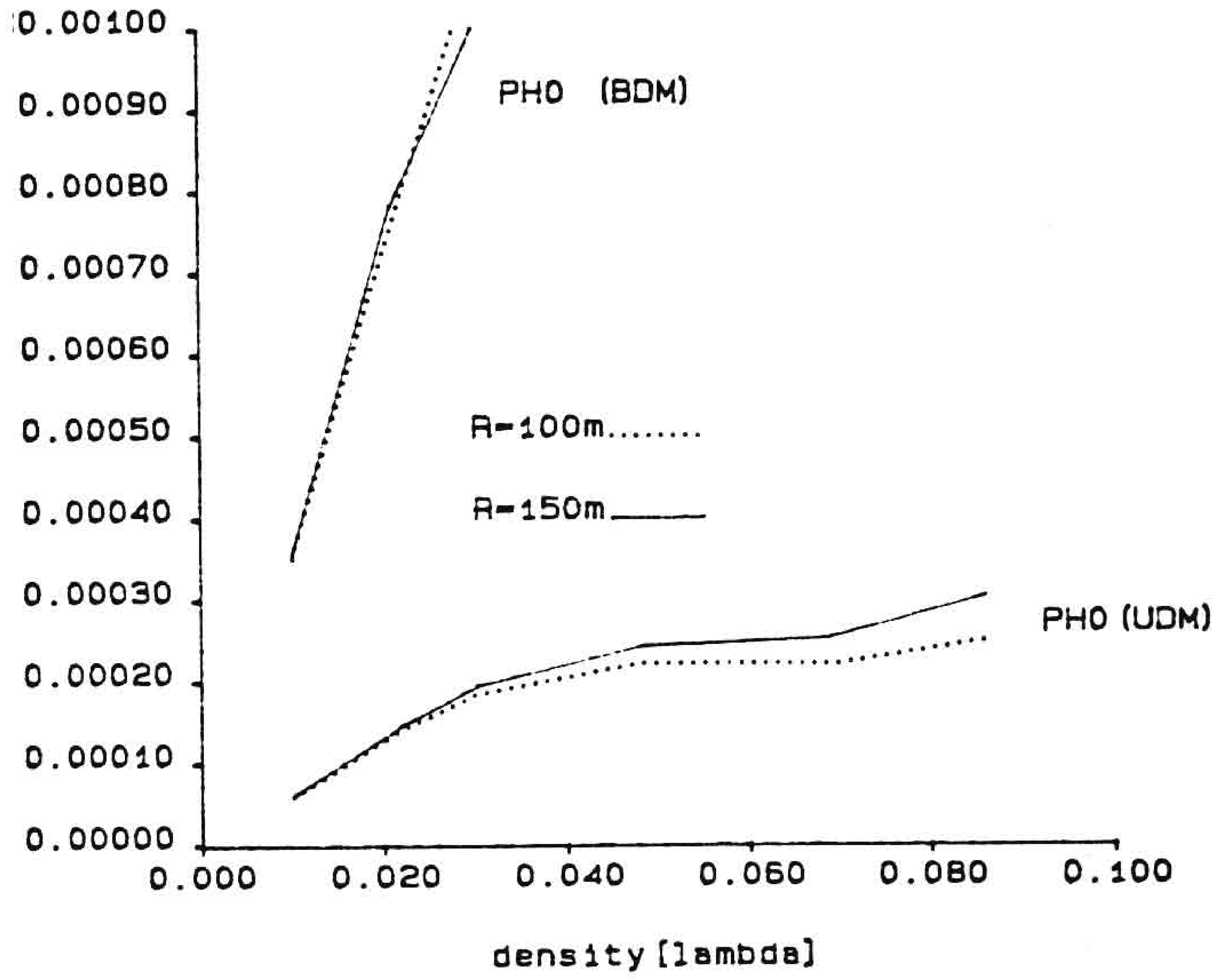

Fig. 9: Probability for a HOR to a station (R=100m,150m) for UDM,BDM

Figure 9 depicts the probability for a HOR to any station. The curves nicely show the stability of the DCAP when used with UDM even in case of high densities. They also indicate the rapidly increasing probability p_{HO}(BDM) for increasing density. As simultaneously performed HO can lead to channel conflicts by reassignment into the same channels - especially in the high density case - the reliability of such channels will degrade to some unknown degree. An exact analysis of such reassignment conflicts is subject of our current studies.

Taking the above values for p_{HO} we find, that DCAP under the control of the ISMA protocol offers highly reliable radio channels over the whole realistic density spectrum. The stability of channels operated under DCAP and the very low HO probabilities for UDM leads us to an improved protocol proposal, named DMAR (Decentral Multiple Access with Reservation). The DMAR protocol, cf. [Hellmich and Walke,1990a] drops continuous transmission of the bit-map, thereby reducing the static protocol overhead of DCAP of about 25% to a dynamic DMAR protocol overhead of about 1% in the worst case. The function of the bitmap is substituted in DMAR by an explicitly requested, demand oriented exchange of channel occupancy information, when needed for handover.

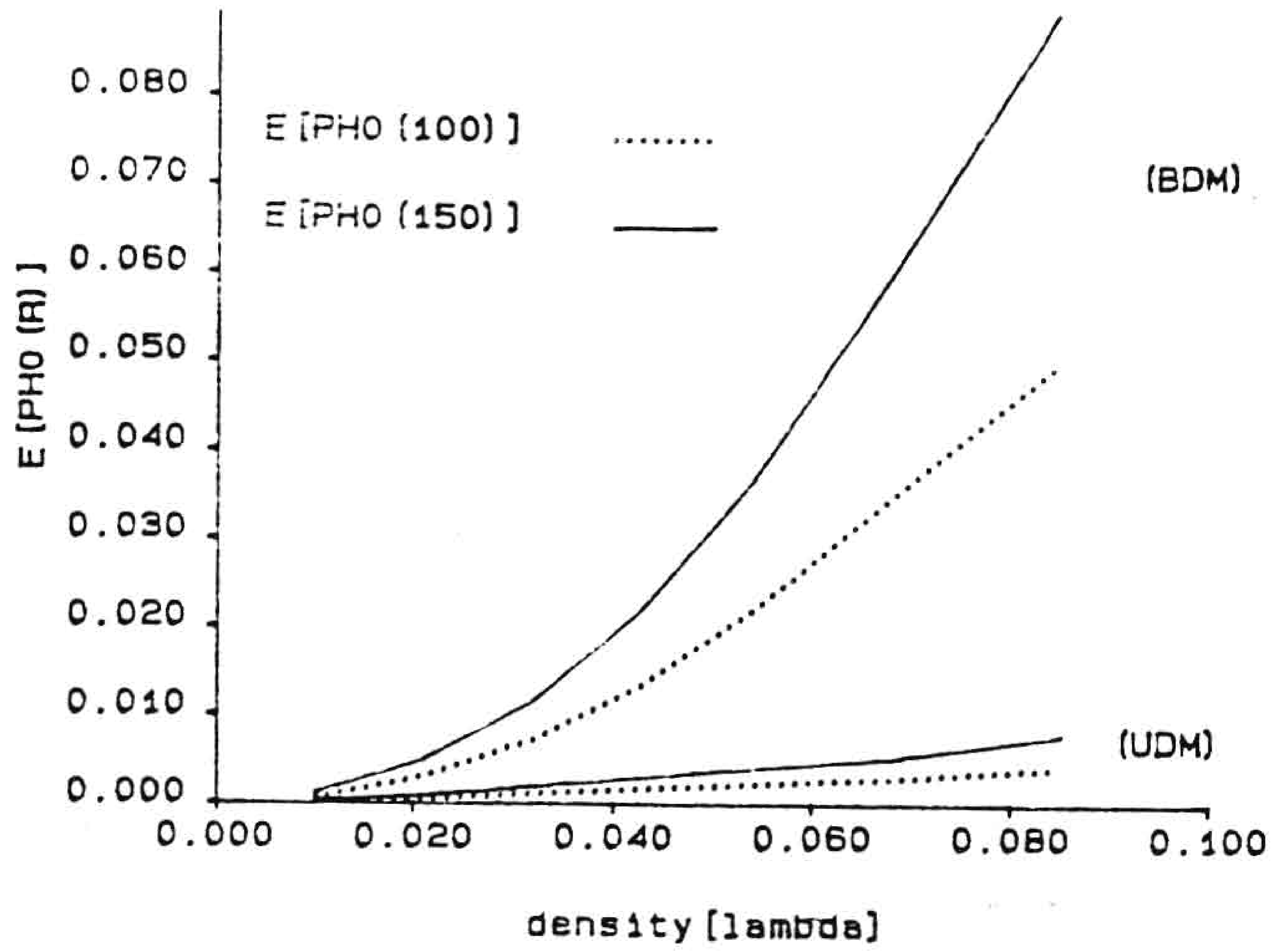

Fig. 10: Expected value for a HOR received by a station during a frame (R=100m,150m) for UDM,BDM

Figure 10 shows the expected value, that any of the stations being in a station's receive range request the channel occupancy information to be able to perform a handover. It is simply derived as

$$E[p_{HO}(R)] = 2\lambda R * p_{HO}(R)$$

under the assumption that each HOR needs a whole slot to be satisfied. The DMAR protocol is very promising since in case of UDM a HO consumes one slot of 125 frames in the worst case (< 1%). With the BDM, one slot of 5-10 frames is consumed.

9 Conclusions

We conclude with a discussion of the promises of the proposed TDMA structure and its access protocols. The main advantage of the integration of different services into one common bandwidth is, that low cost and multi-functional terminal and radio equipment is possible to achieve. It is worth noting, that millimeter waves considered here at 40-60GHz can be substituted by IR without any changes to the ISMA and DCAP protocols.

Another promising feature is, that DCAP is independent of the tx/rx range, which supports the use of adaptive control of the tx range to benefit from space multiplexing. It should be mentioned, that a controlled extension of the subframe XX into another subframe XX' is possible in case of overload of XX. Further the static subframe layout can be adapted to the application's requirements.

Its features favour the ISMA protocol to be applied to a prototype implementation "in the small", which is possible in a modular way by omitting in a first phase the more sophisticated functions like capacity borrowing, subframe handover and high speed channels. Moreover, the ISMA protocol would remain unchanged, if the proposed MAC protocol S-ALOHA would be substituted by any other protocol.

The DCAP protocol has been shown to offer reliable radio channels by immediate handover to a free channel, whenever a channel is observed to degrade unduly in quality. Moreover the number of handovers is significantly reduced, compared to operation without the ISMA protocol.

Our proposals guarantee a high system reliability, due to a totally decentralized organization, and a maximum system capacity per service, due to the adaptive assignment of slots according to the current needs.

Modelling, analysis and simulation of the proposed protocols to determine measures like throughput, delay and channel utilization will be main parts of our future work.

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