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HIGHLY RELIABLE RADIO CHANNELS FOR PROMETHEUS APPLICATIONS

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Zitate /11/, /7/, /13/ weg!

ABSTRACT: A number of future PROMETHEUS services, like controlled overtaking and driving in a file, will require very reliable radio communications 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 stations radio equipment of below 1km, which advantageously supports a spatial reuse of radio channels. Time is assumed to be divided into frames (carrying appr. 2.5Mbit/s) and frames into slots (each carrying 400bit). 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 radio channels, which at the 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 this effect of station's mobility by defining trunks of radio channels being allocated according to the direction the 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 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
- applies carrier-sensing in each station to locally obtain channel occupancy information,
- piggy-backs this information and distributes it as part of each used slot.

The resulting media-access control protocol is presented in detail. It enables each mobile station to locally calculate those channels being unused and interference free in the local environment and therefore being free for access.

1. INTRODUCTION

capacity

We design the management protocol ISMA (Integrated Services MAnagement 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. /11/,/12/. Thereby, a number of potential services and requirements, 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 representant of this is the so-called "PROXIMITY COMMUNICATION" for cars driving in a file, 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 existance of a car internal relative location and distance control facility, the resulting comms. requirements are:
- transmission range up to 50m,
- up to 10 vehicles form a file,
- pure information capacity needed per car is 20byte every 0.5s,
- acknowledged message transfer is required,
- channels have to be highly reliable.

Without a relative location and distance control facility, the update rate increases to ten times per second.

Other services 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 facility, e.g. with a traffic light at a crossing, in order to exercise cooperative strategies. This type of comms. is called "SELECTIVE COMMUNICATION" and the additional requirements are:
- maximal 50 vehicles are communicating simultaneously,
- the channel capacity must be at least 500 bit/s.

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 are also of this type. We propose to perform such updating not periodically, but speed dependant according to a predefined distance travelled (e.g. 10 m), resulting in individual update rates between 0.2 sec (180 km/h) and 1.2 sec (30 km/h).

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 transmit a local road map.

The cumulative requirements for an integrated short-range radio network are as follows:

- both, continuous and bursty traffic, partly acknowledged, 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 with 100 kbit/s capacity 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. There exist a number of well-known media access control protocols, according to different applications, medias, technologies, etc. Taking the mobility of vehicles in our application and their large expected number into account, all protocols using fixed or predetermined access are not applicable. Contention protocols like ALOHA and S-ALOHA are best suited for packet radio networks with a high mobility. They are applicable, however, only for services, requiring small capacities (e.g. one packet) in nonperiodical intervals.

Carrier sensing multiple access protocols like CSMA suffer like ALOHA protocols from the hidden terminal problem, which poses some unreliability on packet transmissions. Moreover, continuous comms, requiring small but constant transmission capacity over some time period, is not feasable using such protocols. So what remain then applicable are protocols applying an implicit or explicit slot reservation using TDMA techniques. They appear to be well suited for applications with a limited mobility of stations which is the case here.

3.1 CSAP REVISITED

/8,9/ proposed a concurrent slot assignment protocol (CSAP), which aims to organize a decentral channel access using implicit reservation according to the R-ALOHA protocol /5/. 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 a so-called observed-information. The observed information is a bit-map of width N, containing all slots marked with '1' where a message from any one-hop distant station was received correctly within the last frame. All other slots are marked with '0'. This information is distributed by each station being active in communication, once per frame. By bitwise OR-ing the received with the observed information each station is able to calculate the so called local information, telling the station, whether a slot (channel) is occupied or free in the two hop environment.

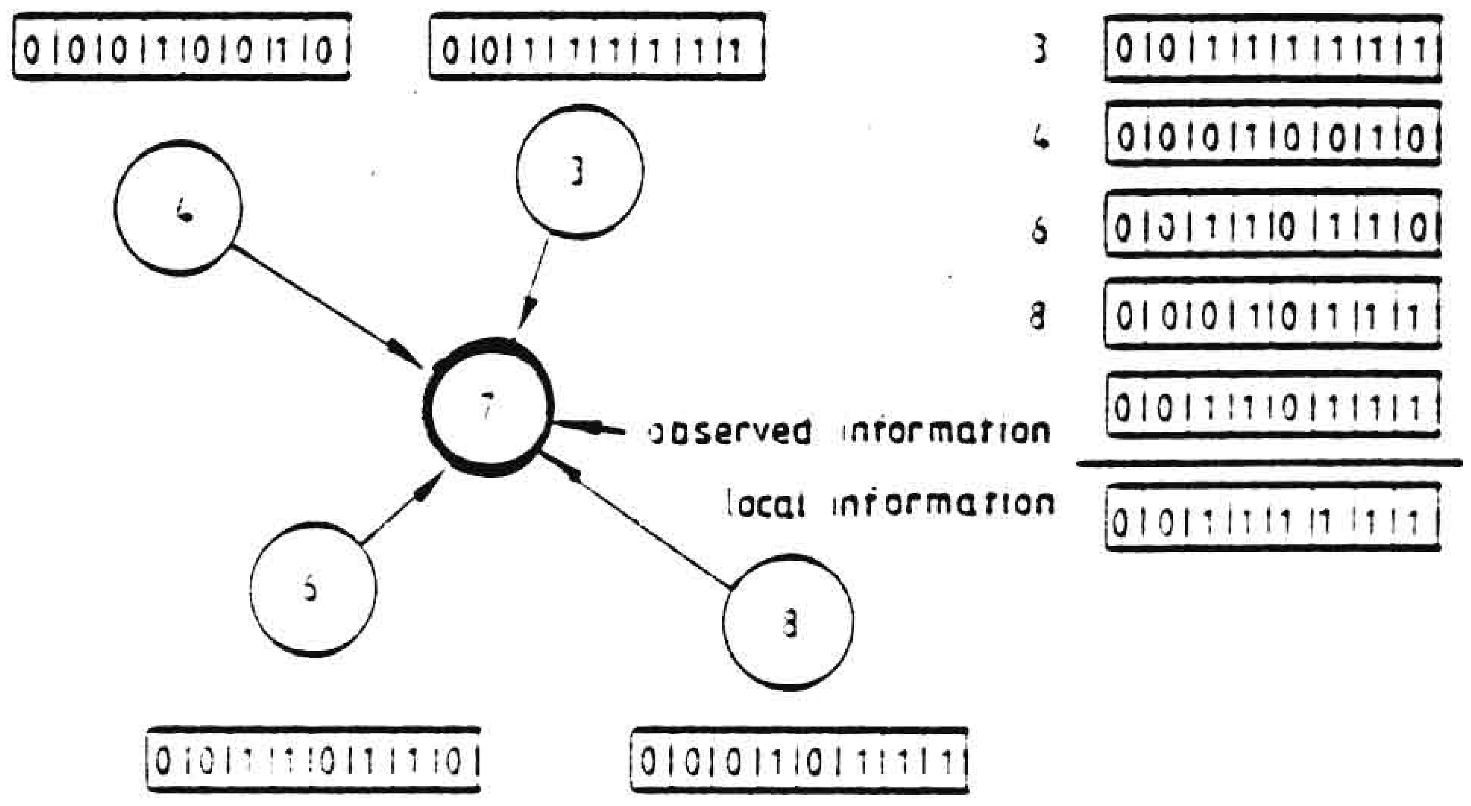

Fig. 1: Local information calculation of station using slot 7, cf. /8,9/

Taking physical and applicational preconditions into account we believe, that a modification of CSAP is necessary to make it workable in the real world. Due to the propagation attenuation of radio waves, in this application it cannot be assumed that all pairs of vehicles are always within their respective transmit/receive (tx/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 (e.g. direction A), cf. figure 2. There, the tx/rx radius R of the stations defines, what stations are neighboured (one hop distant) and what are not.

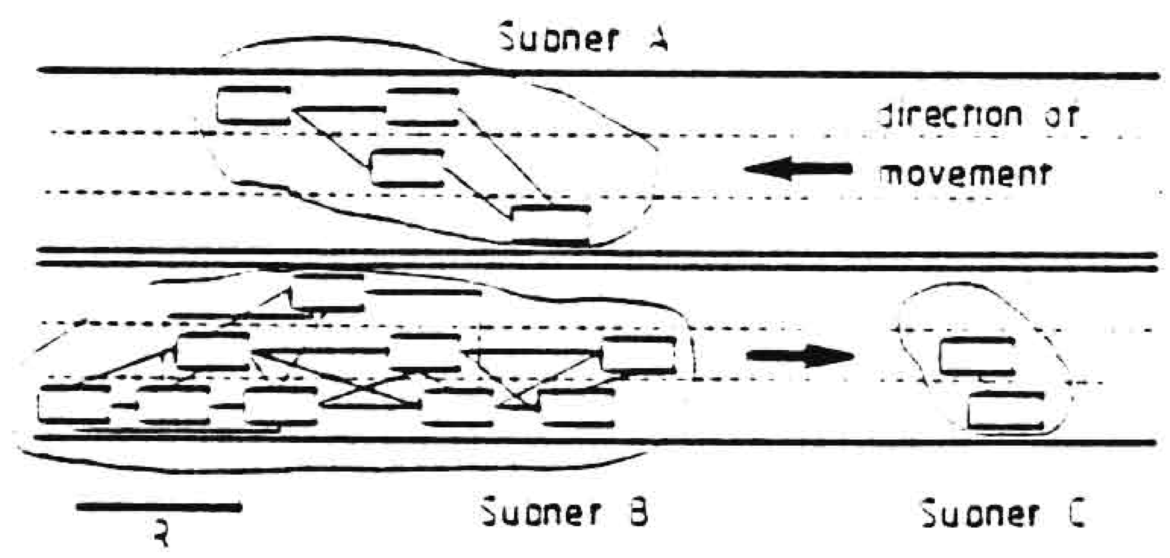

Fig. 2: Example of a three-lane highway. R is the maximum distance allowed for direct comms. between neighbored stations. Due to the ISMA protocol (cf. chapter 6 and 8), no radio interference exists between subnets A and B or A and C.

Unfortunately, a distance greater 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 tx/rx range to sustain a predefined bit error rate (BER). This comms. possibly is disturbed, if station E concurrently receives not only a signal from station S but also from station I.

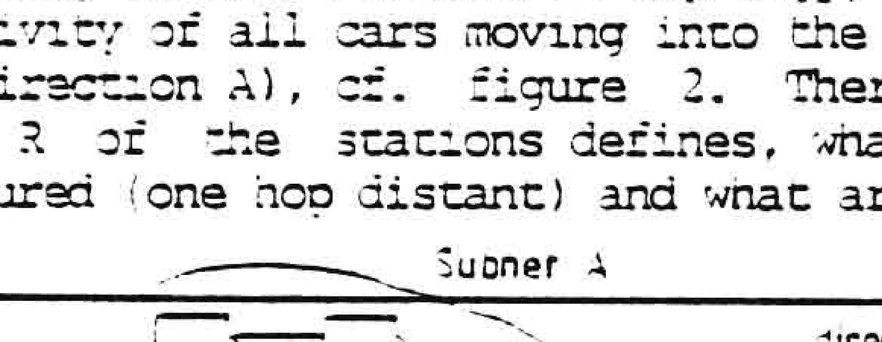

Fig. 3: Interference of the signals of stations I and S at a receiver E. R is the maximum tx/rx range of S to sustain a predefined BER.

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/(D*D), where D is the distance between transmitter and receiver /6/. Simultaneously transmitted signals 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 /X/. 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/occupied) 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. One other shortcoming of CSAP should be recalled also: assuming k channels to be secured, the capacity needed by CSAP is k*k bit/frame. Assuming a frame duration of 100ms and 500 channels/frame, CSAP requires a protocol capacity of 2.5Mbit/s which is unacceptably high. To provide local information for a range of three or more hops using some improved CSAP mechanism following the basic idea of CSAP would at least double the traffic capacity required. In chapter 7 we propose a further development of CSAP which we call Decentral Channel Assignment Protocol DCAP. In conjunction with the ISMA-protocol (defined in chapter 6, 8) DCAP appears to be very promising to meet all the requirements mentioned.

4. PERFORMANCE OF CURRENTLY AVAILABLE MILLIMETER WAVE TRANSMISSION 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 /X/. They are:

- max. distance between transmitter and receiver is about 150m with pan cake diagram (using fan beam antennas, with horizontal and vertical beamwidths of about 30 degrees, the transmission range can be extended up to 1000m),
- bit error rate below 1.0 E-4,
- channel availability due to perticipation is about 99.9%,
- total transmission capacity is about 2.5 Mbit/s .

5. THE PROPOSED TDMA-FRAME

Considering the above mentioned requirements and technical facilities the following seems to be a suitable TDMA-structure. Time is divided into frames and frames into slots. Although we assume global frame synchronization we believe that only neighboured vehicles must be syncronized correctly, whereby it would be tolerable that the start of a frame might be the more different the greater the distance is between any locations. The frame length is 100ms containing 500 slots each with a duration of 200us. A slot contains a 40us header to protect against propagation delays. Subsequently, 400bit follow, about 100 of which are needed for syncronization, packet-header, and error detection/ correction purposes. In case of slots used channel switched, 100bit of the remaining 300bit per slot are assumed to carry protocol data units of the higher layer protocols (ISO layers 3 to 7).

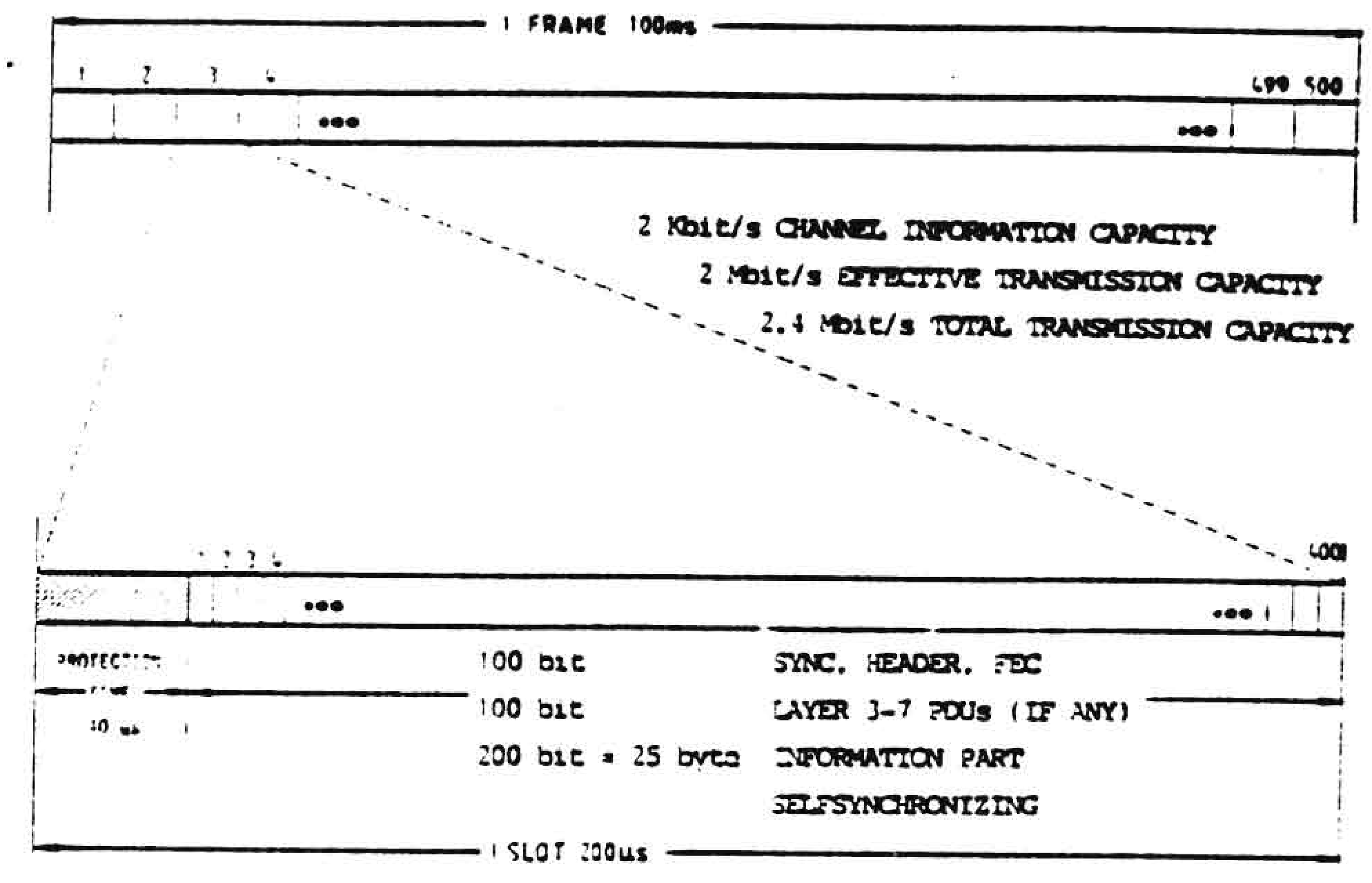

Fig. 4: The proposed TDMA structure

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

6. SLOT ASSIGNMENT TO CONCURRENT SERVICES BY THE ISMA PROTOCOL

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

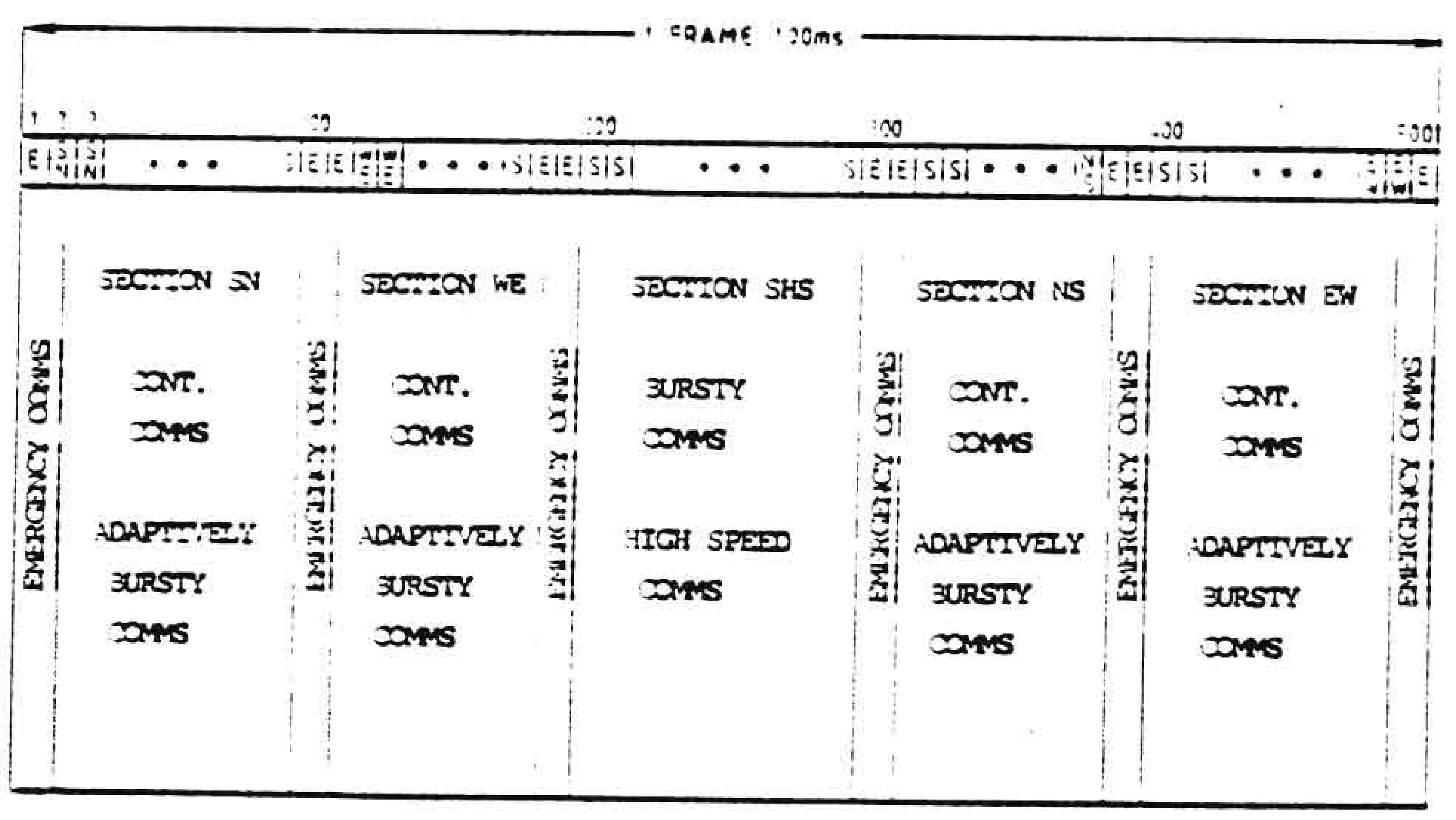

Fig. 5: Static slot assignment by the ISMA-protocol

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. chapter 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 frame capacity allocation it is guaranteed, that radio interference of vehicles moving into different directions is completely impossible.

Moreover, relative mobility of vehicles to each other, which possibly causes interference, is substantially reduced, according to the relative small differences in speed of vehicles moving into the same direction, compared to vehicles moving in opposite directions.

A subframe from slot 200 to 300 is designed to serve bursty comms. demands of all vehicles (independently of direction) by offering random access slots. These slots are mainly used to broadcast local status information of vehicles in quasi periodic intervals. The subframe also provides 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 channel switched subframes, in addition, are available for bursty comms, which is possible under the control of the ISMA-protocol (cf. chapter 3). The packet radio network capacity of the frame is dynamically changing, dependent on the actual channel switched load to the network.

7. DECENTRAL CHANNEL ASSIGNMENT PROTOCOL DCAP FOR CAPACITY MANAGEMENT

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 current occupation of channels to manage a decentrally controlled channel access. Access has always to be deterministical and should bridge the gap between the differing requirements such as reliability and short delay.

We state, that it is impossible for only one MAC protocol to handle all requirements satisfactorily, because they differ too much. Consequently, our approach defines five parameters to support management of the MAC layer, namely (A) received-signal strength, (B) bit error rate observed, (C) trunk occupation, (D) direction of moving and (E) type of service. MAC management comprises the tasks of allocating a deterministic slot/channel of the total available frame capacity to each service demand and assigning the appropriate MAC protocol. This 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 some given margin, e.g. 15dB above the channel noise, resulting in a sufficiently high signal strength to receive with a predetermined low bit error rate (BER).
(ii) between x dB and 15 dB, which appears when two stations are too far distant or that one or more messages are simultaneously transmitted, but decoding is impossible or would result in an unacceptably high BER. On the other hand the signal level is too high to assume locally the channel being not occupied.
(iii) below x dB, which means, that the slot is free at this time.

It is left to researchers working on the physical layer to determine the optimum value of x in dependence on the frequency used.

B) Bit Error Rate: Each station is able to calculate the actual bit error rate (BER) performance by evaluating FEC codes used.

C) Trunk occupancy: Each station transmitting in a channel switched subframe XX (XX=SN,WE,NS,EW) of the ISMA frame continously observes local channel occupancy of its trunk XX as follows: A bit-map, containing one bit per channel of the trunk, is filled according to the received signal strength with a logical '1' in case of A(i) or A(ii) (see above). Otherwise (case A(iii)) a logical '0' is inserted. After performing an OR-operation on all received XX trunk occupancy bit-maps, the local occupancy information is derived reflecting the local view of the station. The bit-map for subframe SHS only contains three bit, (cf. figure 6) indicating which of the three high speed channels have been detected in use by filling in a logical '1' (if any). A high speed channel is used, if in 100 consecutive slots of subframe SHS cases A(i) or A(ii) were detected.

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

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

A), B) and C) define substantial enhancements to CSAP /8,9/; A) to E) define together the proposed protocol DCAP. In applying A) to E), the 'local information' of CSAP, providing a 2-hop local view around each station only is substituted by the local occupancy information of DCAP, which guarantees local access to interference free channels by providing a n-hop local view, cf. eq.(+). CSAP requires application of the so called 'p-mechanism' to determine possible interference, which results in a channel being only partly available for the communicating stations. DCAP does not require a p-mechanism; instead of this the signal strength at each receiver is continuously controlled and a switch-over to another channel is initiated, whenever the current channel appears to be of unsufficient quality. The BER is used as indicator of a bad channel quality in addition. Further, the collision detection mechanism required by CSAP to be applied by assisting stations, together with the transmission of collision indicating slots is not used with DCAP. This is possible because of the substantial reduction of relative speed of all vehicles being potential candidates for collision by devoting channels to the direction of movement. Collisions within DCAP are possible only during phases, when two or more stations collide after deciding to establish a connection, or to switch from a bad channel to a free slot, which apparently is a low probability event, cf. chap. 9. Finally, it should be mentioned, that DCAP can be optimized considering only the receivers local occupancy information instead of the receivers and the senders local occupancy information, due to the OR-operation, cf. C). This variant is currently under investigation.

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 channel in use, thanks to both, the ISMA protocol and the ability to be equipped and able to instantaneously switch-over to a free channel, whenever the current channel suffers from bad quality
- complete and save decentral control
- all benefits of CSAP (cf. /8,9/)
- capability to cope with adaptive tx/rx transmission power

The remaining drawback of CSAP, namely the extensive consumption of channel capacity per slot to distribute channel status information, is solved within the ISMA protocol by assigning to each of four directions of movement a well sized DCAP-controlled TDM-trunk (100 channels each). The combination of A) to E) leads to management strategies, which benefit into high overall system performance. The overhead for transmitting the trunk occupancy bit-maps, is reduced to a quarter of the amount necessary with the CSAP. Apparently, it is quite easy to reduce this overhead capacity further, e.g. a factor of two is possible by introducing eight instead of four directions of movements and a trunk would comprise then 50 slots. By ordering the used channels to be in always known parts of their subframes, the packet radio subframe SHS used for bursty comms. could be allowed to access the actually free slots of the channel switched subframes. So, the capacity of the packet radio part pulsates accordingly, resulting in an optimal performance for the respective services.

8. ASSIGNMENT OF CAPACITY AND MAC PROTOCOLS TO CONCURRENT SERVICES BY THE ISMA PROTOCOL

The task of this chapter is to define, which MAC protocol is responsible for access control in each subframe (EWS, SN, WE, NS, EW, SHS) defined in the ISMA protocol, cf. Fig. 5. At the moment only two MAC protocols are foreseen: S-ALOHA /4/ and DCAP. Thanks to the local information available, each station knows, which slots of the current frame are assigned to the various subframes. The ISMA protocol assigns services to subframes and a MAC protocol per subframe:

- access of subframes SN, WE, NS, EW is controlled by the DCAP,
- the EWS slots/channels again are DCAP controlled,
- the SHS slots are S-ALOHA controlled.

In providing exclusively reserved channels for EWS messages via the ISMA protocol and controlling access through the DSAP, the high priority demand of such services is supported at best. The SHS subframe constitutes the kernel of the packet radio part, where S-ALOHA is used by all subscribers, independently of their direction of movement. Two features in addition are provided there: First, the SHS subframe is able to accomodate up to three high speed channels. They are recognized by listening to all packets of the SHS subframe and indicated by setting appropriate "channel occupancy bits" according Fig. 6(B). This mechanism can be interpreted as the application of the DCAP even for potential high speed channel(s) of subframe SHS.

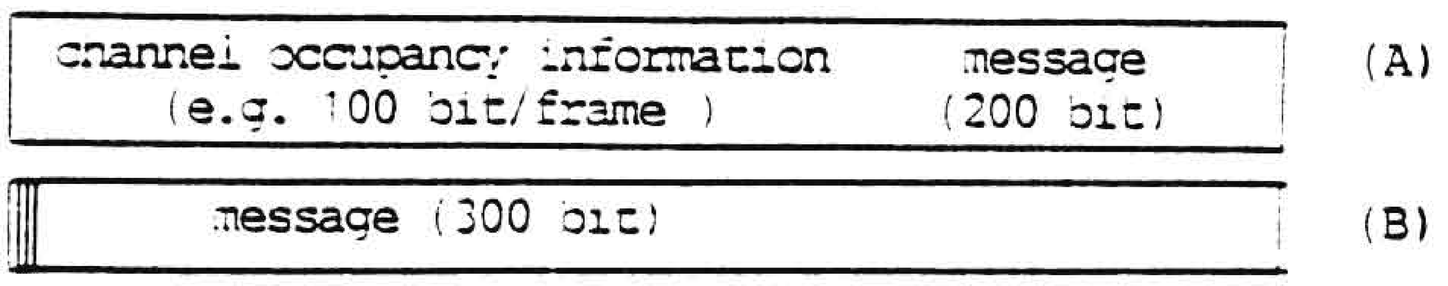

Fig. 6: Structure of messages transmitted in (A) the channel and (B) the packet switched subframes

A second feature is that the capacity of the SHS subframe is increased to the same extent as the cumulative capacity of subframes XX=SN,WE,NS,EW decreases and vice versa. In what follows we propose to use the ISMA protocol to dynamically assign comms. capacity to subframes, resulting in variable trunk sizes.

8.1 DYNAMIC CHANNEL ASSIGNMENT IN ISMA

To realize assignment of channels to subframes XX, according to the actual needs, the currently used channels of any subframe are grouped at one of its two margins. This is indicated by figure 5 by hatched plains. The remaining capacity of the subframes is released for packet radio comms., resulting in a pulsating SHS subframe width. The actually valid margins of this subframes have to be calculated by each station in a way that guarantees, that channels in use are protected against interference. To provide sufficient capacity to establish new comms. relationships, a predefined number of free slots, denoted FREESLOT-FAC, is reserved per trunk. Due to the fact that interference radii are greater than transmission radii a station in a subframe XX can, generally, not decide, whether a '1' bit in a trunk occupancy information map originated from a channel switched or packet switched signal. Consequently, a mechanism is needed to distinguish these two cases. We propose that each station stores in memory the trunk occupancy information of the last frame. It is used to compare it with the actually observed information, in order to derive the trunk occupancy information to be distributed, according to the following rules:

R1: (marking rule)
If a slot of two consecutive subframes XX was detected to be '1', the XX trunk occupancy information is set to '1' for this slot. Otherwise it is set to '0'.

R2: (ordering rule)
Reassign the locally used channel(s) such that none is on the right hand side (for subframes SN and WE) or left hand side (for NS and EW) of FREESLOT-FAC many free '0'-marked channels in the local occupancy information, counted from the left (right) border of XX.

R2 supports a narrow grouping of slots at one margin of a channel switched part and permits the remaining capacity to be used for packet transmission. This rules are fault resistence in the sense, that two stations using by chance the same slot in two consecutive frames for their packets only block this slot for exactly one following frame. The only drawback is that the contention phase during channel establishment is blown up to two instead of one frame because of R1. The following mobility evaluation shows, that this is a very low probability event.

9. MOBILITY AND EVALUATION

Performance evaluation of both protocols ISMA and DCAP does require modelling of mobility. We will compare results from three different models. Two of them assume stations which are randomly distributed in a plane and are driving with constant speed. The third considers the more specific conditions the protocols are designed for. It investigates a stream of randomly on a line distributed stations with all of them having the same direction of movement with their speed being normally distributed. The model's results are compared concerning the probabilities p_i (i=0,1,2, 2) that exactly i new connections occur during dt. These probabilities depend on the distribution and density of stations, their speed (distribution), the size of the transmit radius and the length of the time interval dt. The parameter λ represents the number of stations per square unit in models (1) and (2) and per line unit in model (3), respectively. K represents the total area in a circle with radius R; K=2*R in case of model (3). The first model (1) is taken from /10/, who called it Reduced Mobility Approach (RMA). There an analytical model is used to obtain these probabilities by deriving probability density functions from appropriate plane functions. The second model (2) simulates stations moving in the plane with random direction and constant speed cf. /2/. The probabilities are derived by counting the appropriate events and computing mean values per station and per time interval.

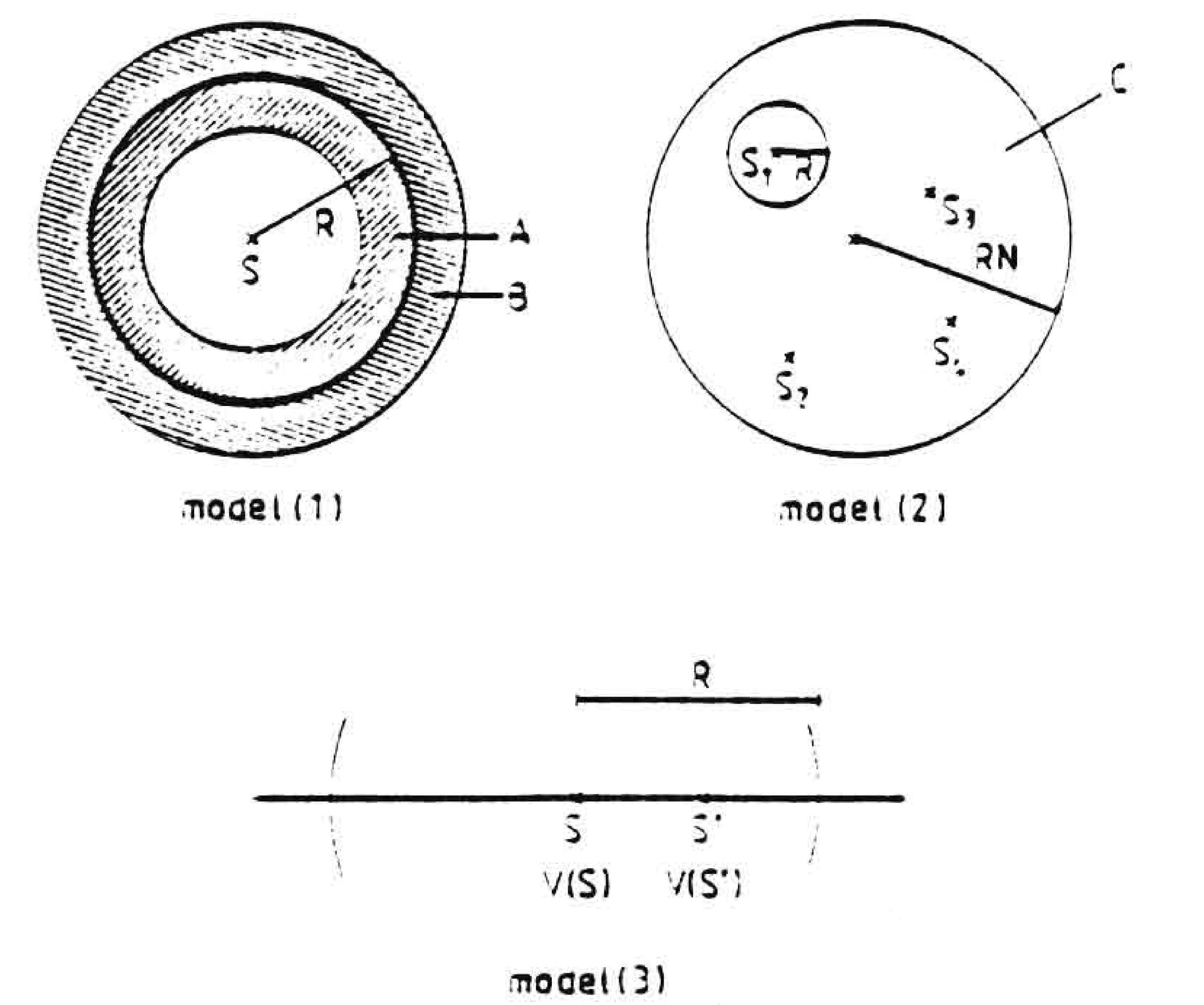

Fig. 7: Model (1) with stations in A being candidates for leaving the rx range of s and B for entering. Model (2), which simulates an infinite net work by reflecting stations potentially leaving the area of C, at their inner circle tangent. Model (3) with equal velocity distributions for all stations moving in one direction.

The third model (3) is investigated analytically using the following assumptions:

- station s' is in the tx/rx radius R of a station s according to the poisson distribution,
- station s has speed v and s' has speed v', both being normally distributed.

For further details cf. /13/. At the moment we are developing a fourth model (4), which is simulative and doesn't have the restriction that all moving stations have a constant or equal speed expectation value. Moreover, this model drops the assumption of models (1) to (3), that stations are independently distributed but simulates vehicular traffic as realistic as possible by taking into account empirical extracted values for vehicle densities and speed distributions measured on german highways, cf. /3/. The movement of vehicles are modelled correlated and driver actions are classified into two categories, one for sportsmanlike and one for more defensive drivers. Models (3) and (4) represent the so called Direction Decoupled Mobility Approach (DDMA). The results of model (4) are not available at the submission date of the paper. The mobility is measured in all the models by the ratio r/R, where R denotes the rx-radius and r

(i) maximum relative distance between two stations after dt time units in models (1) and (2).
(ii) distance a vehicle is expected to drive during dt in models (3) and (4).

This implies that equal mobility for models (1) and (2), compared to (3) and (4) do not have exactly the same basis, but nevertheless are useful to characterize the stations mobility. We do need this to make the different models comparable. Looking at the results, cf. table 1, it is obvious, that the probability of gaining a new connection during dt is much smaller for a linear model (3) of movement than for a model with omnidirectional movement, cf. models (1) and (2). E.g. for r/R=0.01 (0.05) and λK=10 the probability p0, that no other station enters the receive radius of a station during dt increases from 0.944 (0.765) in model (1) to 0.9934 (0.9557) in model (3). Moreover, the results of models (1) and (2) demonstrate the compatibility of these models. However, we have to keep in mind, that the assumptions made are not very realistic.

model	r/R	p0			p1		
	λK	10	20	30	10	20	30
(1)	0.01	0.944	0.892	0.842	0.054	0.102	0.145
(2)	0.01	0.932	0.8735	0.818	0.0655	0.1175	0.160
(3)	0.01	0.9934	0.9869	0.9802	0.0066	0.0131	0.0196
(1)	0.05	0.765	0.570	0.43	0.205	0.320	0.363
(3)	0.05	0.9557	0.9133	0.8729	0.0433	0.0828	0.1187

model	r/R	p2			p*2		
	λK	10	20	30	10	20	30
(1)	0.01	0.002	0.006	0.012	0.0	0.0	0.0
(2)	0.01	0.0024	0.0086	0.017	0.0	0.0004	0.0
(3)	0.01	0.0	0.0	0.0002	0.0	0.0	0.0
(1)	0.05	0.026	0.090	0.153	0.004	0.02	0.054
(3)	0.05	0.001	0.0036	0.008	0.0	0.0003	0.0004

Tab. 1: Dependence of various probabilities of models (1), (2) and (3) on the mobility r/R. Parameter values are: R=100m, dt=0.1s, mean and standard deviation of velocity are vm=10m/s and σ=1.6m.

As no agreed estimates for the traffic behaviour of continous comms. service demands are available at the moment, we have to use rough guesses. Assuming a high comms. traffic load with a station having an expected call interarrival time E[IT] of e.g. 100 frames after giving up a preceding call and an expected call duration E[DT] of e.g. 300 frames, we have an offered traffic per station of ρ=0.75 Erlang. It is assumed there, that a station can have one channel only at a time occupied and that the comms. traffic of a station is independent from other stations. Assuming an interference radius of d=3*R the expected number of occupied channels (OC) in model (3) is

$$E[OC] = \rho * \lambda K' \qquad \text{where } K' = 2 * d, \text{ giving}$$

λK	10	20	30
E[OC]	22.5	45	67.5

As the ISMA protocol provides 100 comms. channels per direction of movement, the expected maximum trunk capacity is satisfyable. Neglecting the possibility, that a message packet of the continuous comms. section of the ISMA protocol could be erroneous, because of FEC and switching of the channel if the BER arises, and making the worst case assumption, that every new connection causes a channel switch, we derive the probability for a channel switch Pcs(r/R, λK) in the DCAP simply as (cf. table 1):

$$Pcs(r/R, \lambda K) = 1 - p0(r/R, \lambda K)$$

which is a low probability event. The expected value E[F], that any of all stations try to allocate a new channel in a frame, is derived as

$$E[F] = \frac{\lambda K' * (1-\rho)}{E[IT] + E[DT]} * Pcs(r/R, \lambda K')$$

This value is important for dimensioning the ISMA protocol parameter FREESLOT-FAC, which is responsible for a good channel access performance using the S-ALOHA protocol. Other performance issues are (static) overhead and efficiency. Defining overhead (O) as the percentage of the transmitted data, which is necessary for a successful transmission and efficiency (E) as the quotient of the pure information data (N) and the total data volume (G), which is N + O + V with V = data lossed, we straightforwardly find that the DCAP's efficiency and overhead evaluate (neglecting V) to

$$E = \frac{N}{O + N + V} = 66.6\% \quad \text{and} \quad O = 33.3\%$$

Refinements of the ISMA protocol aiming at a reduction of the static overhead, may take advantage of research results concerning comms. traffic parameters. It will be investigated, whether the relatively high overhead of approximately 33.3% could be decreased sustantially, by reducing the bit-map control information part, perhaps dependent on the priority of the appropriate services, without loosing the feature of offering very reliable channels, especially for some services like EWS, overtaking, etc.

9. CONCLUSION

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 independant of the tx/tr 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 the pulsation of the packet radio part and high speed channels. The ISMA protocol would remain unchanged, if the proposed MAC protocol S-ALOHA would be substituted by any other protocol. Our proposal guarantees a high system reliability, due to the 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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