

F-COIL

Frame Synchronized COmmunication with Identification and Relative Localization

Th. Hellmich, H.-J. Perz, W. Zhu and B. Walke

FernUniversity of Hagen

Data Processing Techniques

Dept. of Electrical and Electronics Engineering

5860 Iserlohn

1. Introduction

Recently, 23 PROMETHEUS FUNCTIONS were defined.

Several of these functions will require more or less extensive PRO-NET/PRO-ROAD communications to exchange relevant information between vehicles or vehicles and roadside infrastructure equipment.

Especially the functions grouped under the thematic category "COOPERATIVE DRIVING" need a high capacity short range communication network being not available today.

The functions are

- F10 Intelligent Manoeuvring and Control, which means
 - a) to safeguard lanechanges and overtaking manoeuvres,
 - b) to give recommendations for proper behaviour to the driver and for vehicle system in order to improve safety and traffic efficiency.
- F11 Intelligent Cruise Control, which means the harmonization of relative speed and distance between vehicles operating unidirectional in the same traffic lane.
- F12 Intelligent Intersection Control, which means the application of strategies for safe and flow-optimised connection of crossing and merging traffic flows.
- F13 Medium Range Preinformation, which means to supply the driver and vehicle system with early information and relevant static and dynamic data on safety and traffic related occurrences and situations.
- F14 Emergency Warning, which means the warning of the occurrence of an emergency
 - a) to road user in the vicinity of the situation in order to avoid further complications.
 - b) to roadside rescue informations services in order to initiate promptly proper rescue activities.

These 5 functions need a highly reliable vehicle-to-vehicle and vehicle-to-roadside communication channel and F10, F11, F12 and F14 in addition need a precise relative localization of vehicles for a proper working of the functions.

To fulfill the requirements of these functions, we propose a protocol called F-COIL based on PROMETHEUS protocols we have developed and evaluated already imbedded into two frequency bands carrier system serving the functions of vehicle identification and localization.

2. Description of F-COIL

2.1 Protocol Components

In F-COIL we use the following protocols, we have developed for vehicle-to-vehicle and vehicle-to-roadside communication in the PROMETHEUS environment:

- Decentrally controlled frame synchronization protocol in the first layer /ZhWa89/ to support a framed TDM access protocol as a basis to serve the realtime requirements of some of the PROMETHEUS functions.
- MAC (Medium Access Control) protocol for short range vehicle communications /HeWa89/, /RKHW89/.
- Channel capacity management protocol ISMA to achieve the optimal use of the available channel bandwidth /HeWa89/.

The layer structure of these protocols is presented in Fig.1

Layer 2	MAC protocol ISMA protocol
Layer 1	frame synchronization

Fig. 1. Layer structure of the developed protocols

2.2 Transmission Components

The F-COIL contains the following two basic transmission components to support short range communication based on the layered structure:

- Two frequencies and the related transmit/receive equipment are used to support vehicle localization in realtime and to fulfill the realtime communication requirements.
- A timer function is used to measure the signal propagation delay in each communication cycle to calculate the exact vehicle localization.

2.3 Description of Communication and Distance Measurement

To incorporate distance measurement as part of the communication process, the ISMA protocol is presumed to be applied to two frequency bands such that each band contains half of the total system communication capacity. Frame and slot synchronism is assumed to exist between both bands and synchronism is assumed to be performed according to /ZhWa89/, where the tack of the DCF77 radio clock signal /Hilb83/ is used as a time reference.

Following the capacity assignment by the ISMA protocol, each band offers one subsection for packet radio and four sections for direction oriented communication.

A vehicle having no radio contact to others, periodically applies the S-ALOHA protocol to transmit its status and some channel occupancy related information via the packet radio section, as described in our earlier papers. This signals are recognized by others, are evaluated, and - in addition - interpreted as a squitter signal as usual with transponders.

Another vehicle being interested in measuring the relative location of such vehicle opens a channel and establishes a communication relationship with it. This procedure which may follow /HeWa89/, or /HeWa89*/ , has to observe two additional requirements:

1. The initiator of such point-to-point connection must use a slot in one band, whilst the partner's slot must be located in the other band. This requirement follows the usual demand with transponder equipment, that two frequency bands are advantageous to support the preciseness of measurement.
2. A fixed time relationship must exist between the slots used by the communicating partners, which is defined here as an interval, being a multiple (0, 1, 2..) of the slot length and can be individually chosen per connection, but must be communicated to that partner performing the distance measurement function.

The vehicle using the earlier slot (which should not be too far distant from the slot used by the partner, to not degrade precision of measurement) measures the delay from the start of its slot (where its message was sent) to the time instant, where the message of the partner in its assigned slot is observed. The procedure is repeated once per frame.

The result of this measurement is communicated to the respective partner as part of the information part inside messages.

The mechanism described enables all vehicles, communicating on a point-to-point basis, to measure their relative distances during normal communication relationships. It would require that all vehicles being involved in a common activity (overtaking, etc.) must operate a point-to-point channel to all other vehicles being involved in that activity. Assume that n vehicles are involved in such an activity, the number of channels required is $N = n*(n-1)/2$. The number of slots occupied then is $2*N$, according to two slots used per point-to-point connection.

It can be expected that only a small percentage of vehicles are involved at any time and location in a co-operative manoeuvre, requiring the above mentioned full meshing of connections. The others also need distance related information but not on a frame-duration basis. This fact can be used to establish commonly used channels by applying time multiplexing techniques to both support their communication and distance measuring needs. A related proposal, aimed at most efficiently using the channel capacity, is currently under work.

An example of the time relationships of our combined communication and distance measuring protocol is given in Fig. 2.

There a situation is shown where two station A and B are located on a line, seen from the radio clock transmitter DCF77. Two frequency bands are shown where those stations communicate using a point-to-point communication link. The bands are assumed to be in slot and frame synchronism.

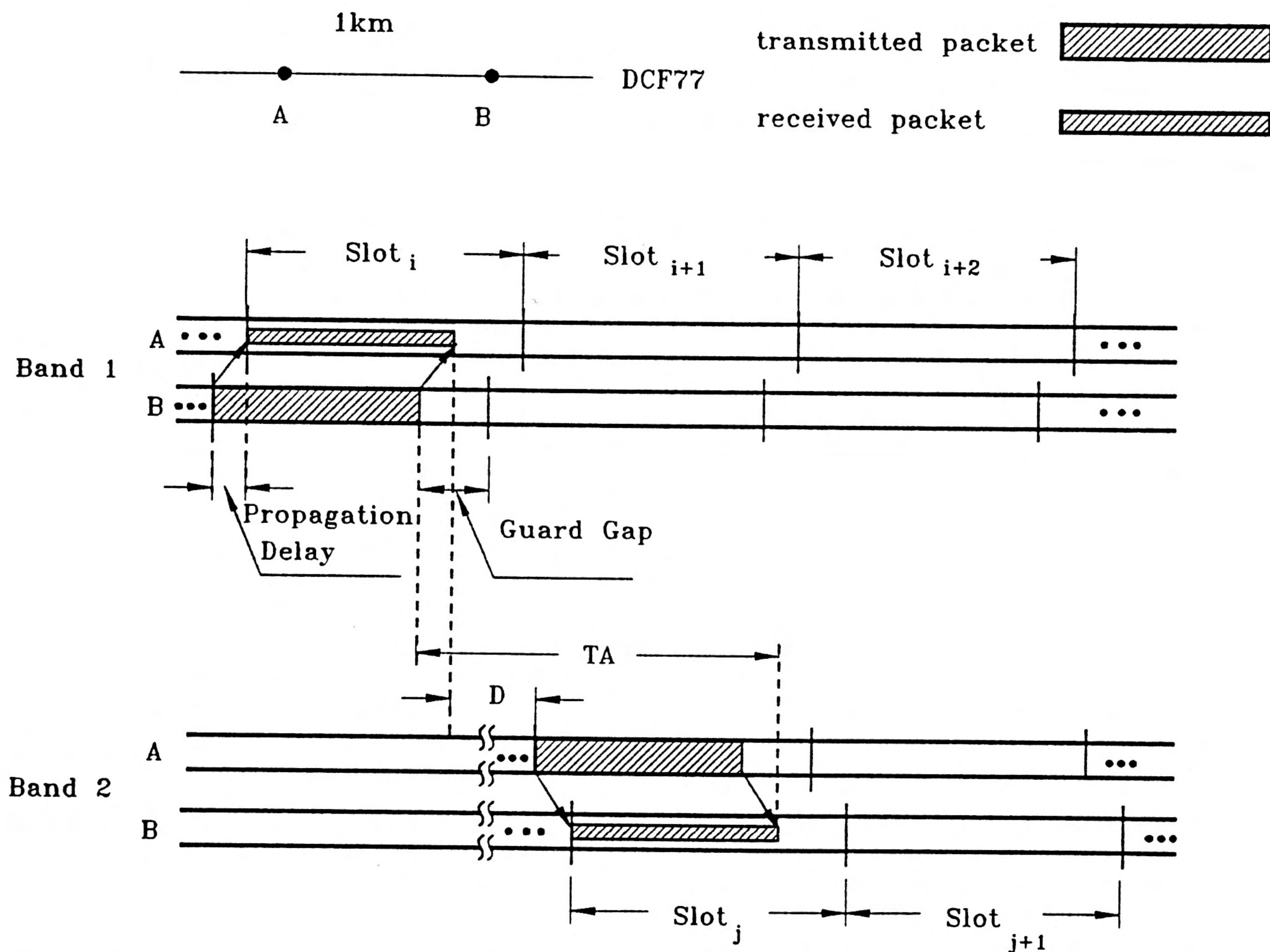


Fig.2 Relative distance measurement with point-to-point communication initiated by station B

The slot begin at the locations of vehicles A and B are different, due to the propagation delay of the clock signal. A packet transmitted by vehicle B is received in the same band after a propagation delay at the receiving vehicle A. Vehicle A uses its own slot which is located in the other band and transmits its packet after a fixed delay D which corresponds to the

different locations of the two transmit slots of stations B and A in the respective frames. Station B knows the time delay applied by vehicle A which is communicated as part of the information carried in the slot. The distance measurement is derived from the total propagation plus transmission delay, say T_A , observed by station B, counted from the end of its packet transmission to the end of packet reception from vehicle A.

3. Performance of F-COIL

3.1 Comparing the throughput of S-ALOHA and F-COIL

To estimate roughly the one-hop throughput of the multiple access protocol DMAR we have to distinguish between static and dynamic overhead of the protocol.

Static overhead (SO) comprises the amount of protocol data bits necessary to let the protocol work properly.

The dynamic overhead (DO) is caused by the protocol data units necessary for channel establishment and channel change (in case of interference).

The static overhead (SO) of DMAR is zero, in contrast to the CSAP and DCAP protocol where a bitmap is needed. To estimate the dynamic overhead we need to know the probabilities for

- (i) new channel connection requests of a station
- (ii) channel change probability of a station
- (iii) channel collisions caused by interference.

(i) is unknown but can be roughly estimated as a low probability event compared to the frame duration. Let A denote the random variable giving the interarrival time between two such events. Let $a = E[A]$ be the expectation value of this distribution.

(ii) and (iii) has been analysed in /HeWa89/ and /ZhHeWa89/. Let p_c denote the channel change probability per station, and p_s denote the probability, that a collision occurs in DMAR.

The DMAR protocol needs two slots to transmit the protocol data to change or establish a channel. Let a slot contain N bit. The one-hop throughput now is a function of the density and the mobility of vehicles. For our rough estimation, we take as an upper bound (worse case assumption) a constant and relative high density of 5 vehicles in 100 m moving with unrealistic high speeds (for this density, cf. /HeHo84/) in one direction. This could be achieved by use of the ISMA protocol, cf. /HeWa89/. Then we could derive:

$$SO = n/N$$

$$DO = (2aN + (p_s + p_c) \cdot 1/a \cdot 2N) / N(1/a)$$

Taking $n = 16$ bit (CRC code), $N = 400$ bit using usual working assumption within PROCOM

$a = 1/500$ (estimated, change requests/slot)
 $p_c = 0.00035871$
 $p_s = 0.00000423$ as calculated in /HeWa89/.

Under the unrealistic assumption of an ideal channel the one-hop throughput (D) per station in this worse case scenario is

$$D = (1 - S_O) + (1 - D_O) = 0.959266 \text{ that means over } 95,9 \%$$

If the channel availability will turn out to be e.g. 98 % the throughput estimation decreases appropriately to 94 % as the percentage of successful transmitted packets per slot per station. For $a = 1/100$, that means that every 10 sec. a station is assumed to need a new channel, we get $D = 0.95$.

Taking D_O out of the calculation, because the values for S-ALOHA don't consider them, our estimation for the throughput is improved to 99.9266% (99.0% respectively).

Results of the throughput of a fully meshed system using the ALOHA protocol are well known /Abra70/.

- S-ALOHA 0.36 maximal network-throughput per slot
- F-COIL 0.95 constant throughput per slot if every channel of a frame is reserved

We can see enourmes differences giving a tendency for the throughput per slot between a fully meshed network with a infinite number of vehicles using the ALOHA protocol and F-COIL although the values are not directly compareable due to the different system assumptions.

For networks with a limited transmission power we can assume an equal ratio for the throughput.

4. Advantages of F-COIL

All requirements of the PROMETHEUS Functions 10 to 14 could be achived by our proposal of integrating the benefits of a synchronous TDM system and a special communication system. Each request includes a message and also each acknowledge, resulting in a duplex data link between two vehicles. Therefore communication between two vehicles can be realized. Broadcast and multicast can be achived by appropriate addresses and is subject of further studies. Identification is performed by using the PROMETHEUS addresses. In the example of 2.3 we can see that the localization is a easy feature of a comunication system with timer. This feature could easily be utilized to enable a decentral adjustable transmission power, resulting in a higher channel reuse factor and in a higher overall system throughput /GoPe89/.

Our capacity management proposal, cf. /HeWa89/, and our Media Access Control Protocol proposals, cf. /HeWa89/ and /RKHW89/, are immediately applicable, resulting in throughput improvements discussed in part 3. Moreover the feature of continuously data streams can be realized, which fulfill real time requirements on a logically reliable basis.

5. References

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