2nd POLISH-GERMAN TELETRAFFIC SYMPOSIUM PGTS 2002

9th Polish Teletraffic Symposium

# COUNTERACTING A PSEUDOPERIODIC MAC CONTENTION STRATEGY USING HASH FUNCTIONS IN NONCOOPERATIVE WIRELESS LAN SETTINGS

Jerzy Konorski*, Maciej Kurant
Faculty of Electronics, Telecommunications and Informatics,
Technical University of Gdansk, Narutowicza11/12, 80-952 Gdansk, Poland
*E-mail: jekon@eti.pg.gda.pl

**Abstract**

A new ECD-hash MAC protocol for wireless LANs has been proposed to protect cooperative stations from stations using greedy deferment selection strategies. Two greedy selection strategies, Optimal Randomiser and Pseudoperiodic, were considered. ECD-hash performance was evaluated via simulation in a full-hearability configuration and compared with an earlier ECD-1s protocol. Both ECD-1s and ECD-hash have been demonstrated to be comparably resistant to Optimal Randomiser, but only ECD-hash was capable of counteracting the Pseudoperiodic strategy.

**Keywords**
wireless network, MAC protocol, noncooperative setting, simulation

## 1. INTRODUCTION

For single-channel ad-hoc wireless LAN systems, it has been argued that the inherent lack of administration and little user accountability potentially create a setting in which a number of noncooperative (greedy) stations self-optimise their bandwidth shares at the cost of the other stations [1]. Suitable modifications of deferment-based MAC protocols were proposed in [3]. In this paper we present a new protocol called ECD-hash, which aims to prevent greedy stations from stealing bandwidth from cooperative ones, and compare it via simulation with an earlier ECD-1s protocol.

Sec. 2 outlines the network model and considered MAC protocols. In Sec. 3, we define an effective greedy strategy for ECD-hash to counteract. In Sec. 4 we describe the results obtained by simulation. Sec. 5 concludes the paper.

## 2. AD-HOC NETWORK MODEL AND PROTOCOLS

The proposed model of an $N$-station single-channel wireless network reflects the general intuition of an ad-hoc system; specifically,

- a station may join or leave at will, thus $N$ need not be known or fixed,
- stations' identities are inaccessible at MAC level, and
- except for detecting carrier on the channel, a station need not interpret any packet of which it is not an intended (uni- or multicast) recipient.

Full encryption of transmitted packets and/or heterogeneous data encoding and formatting across groups communicating stations is thus allowed. We also assume

- single-hop transfer of packets with a full hearability graph, and
- a global slotted time axis.

The former assumption leaves out the complex issue of providing incentives to forward other stations' packets [1]. The latter is to simplify the presentation.

Any station distinguishes v- and c-slots sensed ('void' and 'carrier'); moreover, a recipient of a successful transmission recognises an s-slot ('success') and reads its contents. This binary feedback allows for *extraneous collision detection* (ECD) and is employed in deferment-based MAC protocols e.g., ECD and ECD-1s [3].

### 2.1. ECD and ECD-1s protocols

A station with a packet ready selects a deferment (0..$D$–1 slots) using a *selection strategy*. A winner or a no-winner outcome is established according to a *winner* policy and implicitly announced using a pilot/reaction mechanism which resembles the RTS/CTS handshake in IEEE 802.11 except that pilots only need to be interpreted by recipients and reactions are non-interpretable. Under ECD, a pilot collision terminates a protocol cycle. Under ECD-1s, only stations whose pilots were not reacted to back off until the next protocol cycle, while the rest are free to transmit their pilots in subsequent slots.

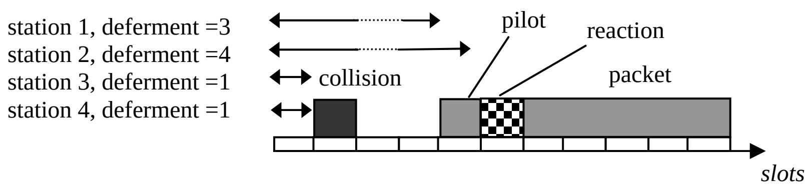


*Figure 1 ECD-1s protocol cycle($N$=4,$D$≥4)*

Under ECD, greedy stations need only a minor alteration of the standard random selection strategy to monopolise the channel bandwidth [3]. ECD-1s is somewhat more resistant to greedy stations.

## 2.2. ECD-hash protocol

ECD-hash aims to improve on ECD-1s in a noncooperative setting. Two types of slots are distinguished:

- *contention slot* – for transmitting 1-slot pilots, and
- *reaction slot* – following an s- or c-type contention slot; does not count as deferment, as indicated in Figure 2

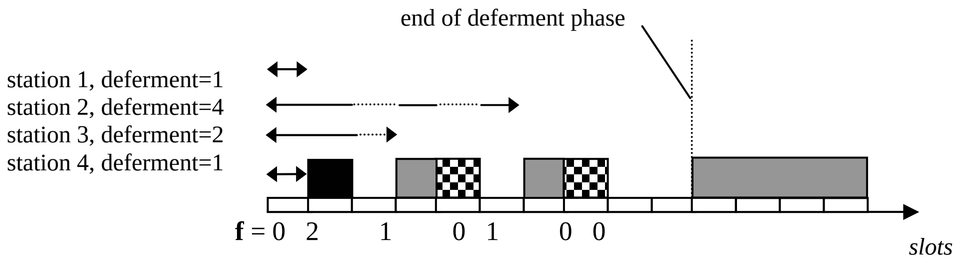


*Figure 2 ECD-hash (N=4, D=7)*

A station with a packet ready defers transmission for a number of contention slots (0..$D$-1), transmits 1-slot pilot and awaits reaction. On sensing an s-slot each recipient transmits a 1-slot reaction burst, while refraining from reaction if a c-slot is sensed. To the other stations, the presence of a reaction indicates a successful pilot, while the absence of a reaction indicates a pilot collision. When $D$ contention slots have elapsed, all stations arrive at an identical *feedback vector* $\mathbf{f}=(f_0 \ldots f_{D-1})$ with $f_i$=0, 1 or 2 if the $i^{\text{th}}$ contention slot was a v-, s- or c-slot, respectively. Denote $S(\mathbf{f})=\{i: f_i=1\}$. All stations then agree on a unique $i^*\in S(\mathbf{f})$, designating the winner station. If $S(\mathbf{f})=\varnothing$ then $i^*=0$ indicates a no-winner outcome. In the example given in Figure 2, $\mathbf{f}$=(0 2 1 0 1 0 0), $S(\mathbf{f})=\{2,4\}$ and $i^*$=1 or 2. This designates station 3 or station 2 as the winner, respectively.

A unique $i^*$ can be agreed on by applying a hash function $H$ into $S(\mathbf{f})$. $H$ should have suitable mixing properties i.e., compute to uniformly distributed values for randomly chosen **f**'s. Three simple hash functions were considered, with $v(\mathbf{f})$ denoting the numerical value whose decimal representation is **f**:

$$
\begin{aligned}
&H_1(\mathbf{f})=v(\mathbf{f}) \bmod |S(\mathbf{f})| \\
&H_2(\mathbf{f})= (v(\mathbf{f}) \bmod 17) \bmod |S(\mathbf{f})| \qquad (1)\\
&H_3(\mathbf{f})=\mathrm{round}(\pi\cdot v(\mathbf{f})) \bmod |S(\mathbf{f})|,\ \text{where } \pi=3.14159265358979
\end{aligned}
$$

In preliminary simulations, both $H_2$ and $H_3$ proved satisfactory and $H_3$ was taken for further experiments.

## 3. SELECTION STRATEGIES

To devise a selection strategy we have to constrain the way in which a greedy station can 'forge' winning deferments to self-optimise. Suppose the greedy station decided to use its own method of selecting a deferment instead of a random number generator. This action would be impossible to detect and prove by other stations. Our objective is to develop a MAC protocol in which no rational selection strategy will perform substantially better than a standard one, based on a random number generator. Other types of forgery are discussed elsewhere [3]. Noncooperative behaviour is further accounted for as follows:

- all stations adhere to a common winner policy,
- *G* out of the *N* stations are greedy i.e., free to use greedy selection strategies (*G* need not be known or fixed),
- the other *N*–*G* stations (called *regular*) use the Randomiser strategy, and
- greedy stations are *isolated* i.e., cannot coordinate their selection strategies with other greedy stations.

The difference between the Randomiser strategy and those used by greedy stations is that the former attempts to optimise the overall bandwidth utilisation, whereas the latter are self-optimising. Because self-optimising strategies do not form a definite set, suitable heuristics should be sought.

### 3.1 Randomiser

Randomiser is a regular stations' strategy. It can also be applied by greedy stations e.g., when the greedy strategy being used does not perform satisfactorily. Deferments are drawn at random according to two types of probability distribution: uniform and 'aggressive;' the latter is given by a convex quadratic function i.e., Prob(selected deferment=$l$) = $const.\cdot[1+(l-D+1)^2]$, which favours short deferments.

### 3.2. Optimal Randomiser

In this case it is assumed that all *G* greedy stations select transmission deferments at random, using a common probability distribution **d** that maximises the obtained bandwidth. For numerical experiments, random search was applied instead of determining **d** analytically, starting from the uniform distribution. In each of 10,000 steps, 0.05 was tentatively subtracted from one randomly chosen element of the distribution and added to another, with the new values only retained if yielding increased bandwidth for the greedy stations.

Note that Optimal Randomiser violates the *isolation* constraint since **d** is assumed common at all greedy stations. It is primarily used to estimate the worst case from the regular stations' viewpoint.

### 3.3. Pseudoperiodic strategy

Suppose the $G$ greedy stations are not subject to the isolation constraint. Firstly, they will arrange to select different deferments to avoid pilot collisions. Secondly, under ECD and ECD-1s, short deferments will be preferred. For $G$=4, a strategy in Figure 3 may be conceived. In the absence of regular stations it would amount to token passing from one greedy station to another. The sequence of token holders would be periodic, with period $T$=5. The presence of regular stations may disturb this, but only upon pilot collisions in the first four slots.

| | $DP_1$ | $DP_2$ | $DP_3$ | $DP_4$ | $DP_5$ |
|---|---|---|---|---|---|
| greedy 1 | 0 | 3 | 2 | 1 | 3 |
| greedy 2 | 1 | 0 | 3 | 2 | 1 |
| greedy 3 | 2 | 1 | 0 | 3 | 0 |
| greedy 4 | 3 | 2 | 1 | 0 | 2 |

*Figure 3 Periodic token passing – deferments chosen by greedy stations; $G$=4, period $T$=5, $DP_1..DP_5$ – five successive deferment phases*

Figure 3 exemplifies a Nash equilibrium point [2], i.e., none of greedy stations can individually improve its performance. The equilibrium is not fair in that the greedy stations are not guaranteed equal shares of the bandwidth (greedy station 3 will probably obtain the largest on account of its double 0-slot deferment). Taking only the first four columns and $T$=4 yields symmetry in the deferment distribution as well as the obtained bandwidth shares.

The following Pseudoperiodic strategy aims to reconcile the isolation constraint with the idea of token passing. Each greedy station applies a periodic sequence of deferments $\mathbf{s}=(s_1\ \ s_2, \ldots\ \ s_T)$, $s_i \in 0...D$-1, in successive protocol cycles ($s_5=3$ means 3-slot deferment in the 5$^{th}$ cycle). Denote by $e_i$, $e_i \in 0..1$, the long-term frequency of winning the $i^{th}$ cycle. At the end of each period, the $e_i$'s are calculated using the exponentially weighted moving average:

$$\underset{i\in 1..T}{\forall} e_i = \alpha \cdot e_i + (1-\alpha)\cdot last_i \tag{2}$$

where $\alpha \in 0..1$ and $last_i$ equals 1 if the $i^{th}$ cycle was won and 0 otherwise. Subsequently, with a fixed probability, the worst-performing selection is modified i.e., $s_{i*}$ is replaced by a new randomly chosen value if $e_{i*} = \min\{e_1, e_2, \ldots, e_T\}$. Such a selection strategy permanently improves the obtained bandwidth share.

Technically, the isolation constraint is not met: the greedy stations have to apply identical $T$ (or its multiple); lack of synchronisation will inevitably lead to more frequent collisions. Nevertheless, the choice of $T$=$D$ seems natural; one can also imagine a version of the Pseudoperiodic strategy with optimisation of $T$.

## 4. PERFORMANCE EVALUATION

In a series of simulation experiments, regular and greedy stations were contending for access to the transmission medium under heavy load (all stations always had packets to transmit). This latter assumption created a traffic environment typical of competing multimedia streams, an ideal scenery for 'bandwidth stealing.' In all simulations, a fixed number $N$=10 of stations was used, with a variable number of greedy stations ($G \in 0..N$). Packets were of fixed length $L$=50 slots and $D$=10 was taken.

In Figure 4, the average bandwidth obtained by regular stations, denoted by $U_r$, is plotted against $G$ under ECD, ECD-1s and ECD-hash protocols. Regular and greedy stations applied the Randomiser and Optimal Randomiser strategies, respectively. $G$=0 corresponds to an all-cooperative setting; $U_r$ is then slightly lower than 10% (or 1/$N$) of the total bandwidth due to the scheduling penalty; this effect is stronger for ECD-hash. In a noncooperative setting ($G$>0), $U_r$ is even lower under ECD and ECD-1s. While the former protocol seems unacceptable, the latter seems to cope with the presence of greedy stations fairy well, especially when the 'aggressive' version of Randomiser is used. ECD-hash, unlike ECD and ECD-1s, holds its own regardless of $G$. The reason for this is that under ECD-hash, any favouring or discriminating a particular deferment causes more frequent pilot collisions. Thus the uniform distribution is optimal and consequently, the selection strategies of regular and greedy stations are identical.

After the simulation, the sequences **s** at the greedy stations were inspected to find that they resembled that in Figure 3. The greedy stations, none of which having knowledge of the number or status of other stations, managed to establish a token passing sequence.

Figure 5 presents the results of simulations where regular stations used the Randomiser strategy, while greedy stations used Pseudoperiodic. For the Pseudoperiodic strategy, $T$=$D$=10 and $\alpha$=0.95 were fixed. The value of the latter parameter makes **e** dependent on the last few dozens of periods.

Observe that as $G$ increases, the Pseudoperiodic strategy turns out increasingly effective for the noncooperative stations, reflecting the fact that the token passing scheme inherently avoids pilot collisions, whereas the Randomiser strategy does not. However, this effectiveness depends on the chosen protocol. ECD is definitely not resistant to the Pseudoperiodic strategy; ECD-1s is uniformly superior to ECD, although for $G$>0.4·$N$ the results are comparably unsatisfactory. The dotted line corresponds to the 'aggressive' version of Randomiser applied at regular stations under ECD-1s. A better performance for $G \leq 0.4 \cdot N$ is observed here; still, the range of unfavourable $G$ remains the same. ECD-hash prevents the cooperative stations cut-off even for larger $G$, but it sacrifices the all-cooperative bandwidth utilisation due to the increased protocol overhead. Even though this deficiency is somewhat exaggerated in Figure 5 on account of a relatively small packet size assumed (50 slots compared with *D*=10), it may sometimes be a factor, especially under heavy traffic conditions.

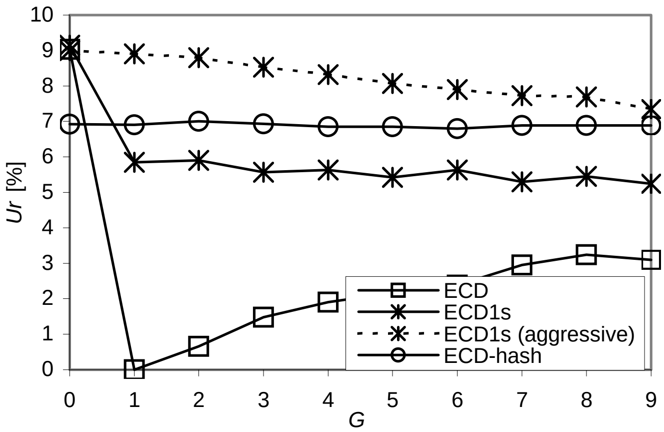


*Figure 4 Optimal Randomisers vs Randomisers: minimum guaranteed bandwidth vs. G*

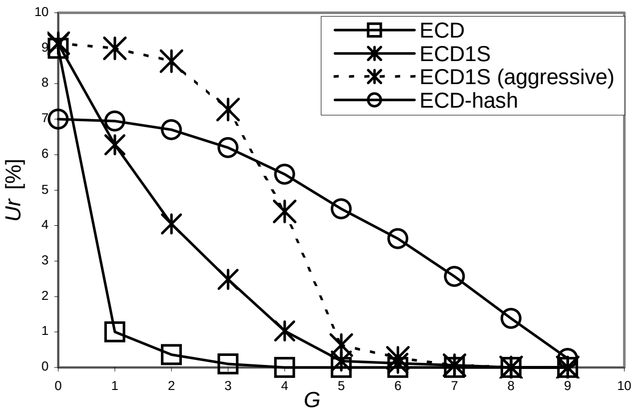


*Figure 5 Pseudoperiodic vs Randomisers: minimum guaranteed bandwidth vs. G*

The results presented in Figure 5 were unfolding gradually – at the beginning, the performance of greedy stations was comparable to regular stations'. In all cases, it took greedy stations less than 200 periods (or 2000 protocol cycles) to stabilise their bandwidth at a high level. Assuming that each deferment phase is followed by a 1500-byte packet over a 10 Mb/s link (both values are realistic within the IEEE

802.11 standard), the convergence time of Pseudoperiodic strategy equals 2.3 s. Thus a few seconds time seems long enough to threaten regular stations even in changing traffic conditions. This raises the question, If the Pseudoperiodic strategy is so effective, why should it not be applied by regular stations? The version of algorithm presented above cannot become a regular stations' strategy, because

- it is not necessarily fair to the stations using it, the resulting bandwidth distribution being heavily dependent on the initial sequences **s;** in some extreme cases, individual greedy stations were observed to perform worse than regular ones
- it is not resistant to some simple selection strategies e.g., if a station always selects a 0-slot deferment, the Pseudoperiodic strategy will be left with longer deferments and a zero bandwidth share.

## 5. CONCLUSION

A new ECD-hash MAC protocol for wireless LANs has been proposed to protect regular stations from stations using greedy deferment selection strategies. Two such strategies, Optimal Randomiser and Pseudoperiodic, were considered; the former self-optimises the probability distribution of selected deferments; the latter attempts to establish a token passing-like scheme among greedy stations. ECD-hash was simulated in a full-hearability configuration and compared with an earlier ECD-1s protocol. Both protocols are comparably resistant to the Optimal Randomiser strategy, but only ECD-hash is capable of counteracting the Pseudoperiodic strategy. Research is underway to adopt the Pseudoperiodic strategy at regular stations and to cover partial-hearability configurations.

## BIBLIOGRAPHY

[1] Buttyan, L., Hubaux J.P., *Nuglets: A Virtual Currency to Stimulate Cooperation in Self-Organised Mobile Ad-hoc Networks*, Tech. Rep. DSC/2001/001, Swiss Federal Institute of Technology, 2001

[2] Kalai E., Lehrer E.,, *Rational Learning Leads to Nash Equilibrium*, Econometrica, Vol. 61, pp.1019-1045, 1993..

[3] Konorski J., *Random Token Access Protocols in a Noncooperative Setting under Heavy Load*, Arch. Theor. Appl. Comp. Sci., Vol. 13, pp. 259-272, 2001

[4] Lazar A.A., Semret N. *Auctions for Network Resource Sharing*, Tech. Rep. CU/CTR/TR 468-97-02, Columbia Univ. 1997

[5] Natkaniec M., Pach A. R.: *A Performance Analysis of the IEEE 802.11 Networks in Presence of Hidden Nodes*, Proceedings of Personal Wireless Conference 2000, Gdansk, Septemter 2000, pp. 157-168