Random Packet CDMA: Reducing Delay and Increasing Throughput of WLAN Systems

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***Abstract*— We revisit Random Packet Code Division Multiple Access (RP-CDMA), a recently proposed Physical/MAC layer scheme for wireless CDMA networks. We revise earlier results by adopting a more realistic Spread Aloha model for header transmission and packet sizes with distributions typical for Internet2 traffic. Thanks to timing recovery in the RP-CDMA header and greatly reduced packet collision probability, unlike Spread Aloha, RP-CDMA enables the use of multiuser receivers for data detection. We simulate the throughput characteristics of RP-CDMA with the matched filter, the decorrelator, the MMSE and partitioned spreading demodulation detection and compare performance to Spread Aloha in a base station centric network.**

***Keywords:* Random Packet Networks, RP-CDMA, Aloha, Spread Aloha, CDMA, Partitioned Spreading, Multiuser Detection**

I. Introduction

Fundamentally, channel access can be performed either in a centrally controlled or distributed, random fashion. The benefit of scheduled access is obvious: due to the all-knowing nature of the channel arbiter (i.e., the base station), packet collisions can be avoided and service can be guaranteed [1]. However, as a result of necessary signaling, scheduled access is best applied to circuit-switched systems, where incurred overhead occurs only at the initialization and termination phases of a connection [2]. With packetized data, scheduled access either leads to large overhead and delay due to negotiations on a per-packet (or few-packet) basis, or to low efficiency if packets are merely routed through established circuits. As a result, distributed, “handshake-free” random channel access has not only attracted considerable attention in data networks, but has in fact conquered this scenario. As an example, in packetized data networks where channel sensing is possible, the IEEE 802.11 standard has sparked a breakthrough of wireless technology. Where sensing is not feasible, random access is typically facilitated through the Aloha protocol or one of its flavors [3], [4]. Such environments include networks with large propagation delay, for instance satellite communication systems. Unfortunately, the lack of sensing greatly reduces achievable throughput [4], [5].

RP-CDMA or Random Packet Code Division Multiple Access is a recently proposed [6] random transmission scheme which has been designed to overcome the restrictive nature of the Aloha method. As has been shown in [6], RP-CDMA has the potential to greatly improve system throughput and to approach the goodput[1] of scheduled channel access. This is achieved by a reduction of the probability of packet collisions combined with the facilitation of multiuser technology for data detection. Furthermore, the performance of RP-CDMA can improve with the capabilities of the base station, no modifications in the transmitter are necessary. In RP-CDMA, a transmitted packet of length $(L_\mathrm{h} + L_\mathrm{d})$ consists of header and data portions as illustrated in Figure 1. The header frame of

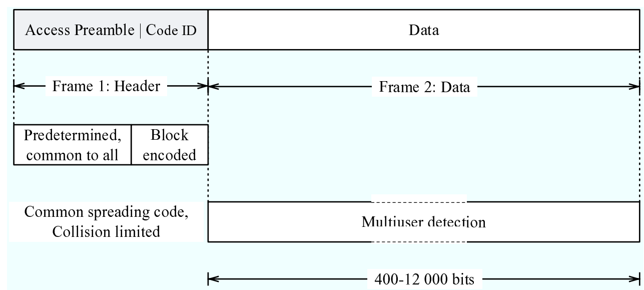

Fig. 1. RP-CDMA packet format as proposed in [6].

length L_h consists of the access preamble necessary for packet detection and carrier as well as timing recovery. The headers are all spread with a unique spreading signature which is known universally and contain the randomly chosen spreading information (Code ID) used to encode the data portion of the packet. For the data portion, the probability that any two active frames employ identical spreading sequences which would lead to collisions can be made arbitrarily small by increasing the Code ID. The header sequence enables the base station to detect ongoing concurrent transmissions and to recover timing information for each packet, allowing RP-CDMA to be fully asynchronous. Essentially, the header channel operates a Spread Aloha system under extremely low load, thus facing a very low probability of packet collisions; whereas data transmission occurs under 3G CDMA system-like conditions.

In [6], the system characteristics of RP-CDMA have been investigated under the assumption of a collision-limited Aloha header process, setting the effects of multiuser interference aside. In addition, no method for the detection of the data frame of the packet was introduced or discussed. Instead, it was assumed that as long as the headers survived, successful recovery of the entire packet is guaranteed. Also, unreasonable sizes for the data frame of the RP-CDMA packet in the order of hundreds of thousands of bytes were required to improve throughput. As a result of these specific assumptions, it was concluded that RP-CDMA allows to approach the capacity of the multi-access channel and system performance is only limited by the capabilities of the base station in terms of the

[1] “raw” channel capacity minus signaling overhead

number of decodeable concurrent transmissions.

In this paper, we extend earlier analysis [6] in the following ways. We suggest that the RP-CDMA packet format separates the wireless channel into a virtual channel for header and data transmission and model the header as a Spread Aloha packet. From here, header transmission faces two limitations: *(i)* a collision limitation on the chip-level due to identical header spreading sequences, and *(ii)* an interference limitation by concurrent header and, especially, data transmissions. In addition, we investigate the behavior of the matched filter, the MMSE, the decorrelation receiver as well as partitioned spreading demodulation detection for the data frame of the RP-CDMA packet. As a result, we present more detailed and realistic results for the the possibilities as well as limitations of RP-CDMA header and data transmission than those derived in [6].

II. Preliminaries

A. Notation

We denote the processing gain by N with subscripts d indicating RP-CDMA data and h indicating the RP-CDMA header; similarly N_{SA} indicates the spreading gain of Spread Aloha. The length of the RP-CDMA header and payload frames are denoted as L_{h} and L_{d}, respectively. Γ is used to denote the signal to noise plus interference ratio (SNIR) at the output of a receiver, and γ refers to the detection threshold. K denotes the overall network population, out of which n users are active at a given time. We assume fixed bit durations; accordingly, when the processing gain N is increased, the chip size reduces proportional to $1/N$ and the required bandwidth increases proportional to N. As a result, any increase of N constitutes a loss of bandwidth efficiency.

B. CDMA System Model

We assume $1 \leq n \leq K$ active users with independently generated binary information bits $b_k \in \{0, 1\}, k = 1, ..., n$ and modulated by n signature sequences $\{s_k(t)\}_{k=1}^{n}$. As is common in the literature and for mathematical purposes only [7], we assume chip syncronicity. The transmitted signals are embedded in an additive white Gaussian Noise (AWGN) channel and the received CDMA signal is

$$y(t) = \sum_{k=1}^{n} \sqrt{P_k} x_k(t) + \nu(t) \tag{1}$$

where P_k is the energy accumulated in a symbol interval for user k, $\nu(t)$ is zero mean white gaussian noise with two-sided spectral density σ^2, $x_k(t) = \sum_i b_k(i) s_k(t - iT)$ and T is the bit interval.

C. Traffic Model

For easy performance comparison to results reported for Aloha in the literature, we adopt the model used by Abramson in his original papers on the performance of the Aloha method [3], [8]. There, it is assumed that packets are generated independently according to a Bernoulli process at maximum rate $\lambda = 1$, and packets are transmitted with probability $p(\mathrm{trans}) = 1$, i.e., as soon as a packet is ready for transmission, it will be transmitted. Interestingly, very recently, Naware *et al.* [5] found that as soon as multi packet capture is available at the receiver, $p(\mathrm{trans}) = 1$ is in fact delay and throughput *optimal*. From a systems angle, we also believe it is very reasonable for an RP-CDMA implementation to immediately transmit packets as they enter the nodes queues as an approach to reduce transmission delay – comparable to *1-persistent CSMA/CD*, see for example [9].

III. The Performance of RP-CDMA Header Detection and Similarities to Spread Aloha

The successful reception of a user packet in RP-CDMA requires correct header as well as correct data detection. We examine these factors individually, noting that packet transmission can be separated into two virtual channels – a header and a data channel, see Figure 2. For one, header reception is affected by packet collisions on the chip-level of overlapping headers due to the system-wide identical header spreading sequences. In addition, because of the concurrent nature of packet transmissions, header detection has to operate under heavy interference. As follows immediately from the fact that $L_{\mathrm{d}} > L_{\mathrm{h}}$, this interference is mostly caused by data portions of competing packets. While in these two aspects similar to Spread Aloha, in RP-CDMA, increasing the ratio $L_{\mathrm{d}}/L_{\mathrm{h}}$ reduces collision effects. Moreover, by boosting the header transmission power over the power of the data portion, the probability for correct header detection can always be improved.

We use Spread Aloha as the base line for our performance evaluations. The reasons for this are two-fold. Firstly, Spread Aloha is a very well known random, physical and medium access control (MAC) protocol. Secondly, the RP-CDMA header essentially operates a Spread Aloha system under very low load. Clearly, a thorough understanding of its behavior is substantial to the successful evaluation and proper modeling of RP-CDMA. If we assume that the packets' SNRs are such that

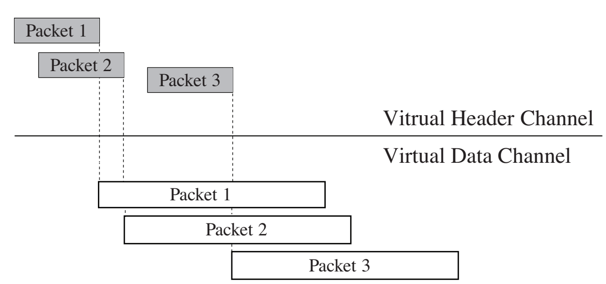

Fig. 2. Traffic in the virtual header and data channels. Since $L_{\mathrm{d}} > L_{\mathrm{h}}$, interference for header detection is mostly generated by header/data *(h/d)* overlaps from other users' packets. This is shown in the case of the header of packet 3, which does not face *(h/h)* interference, but has to be captured in the presence of the data portions of packets 1 and 2.

power capture is impossible[2], we can express the probability

[2]In this context, the term *power capture* refers to the effect that if the power differential between two packets is very large, even if they are subject to header collisions, one packet may be recovered successfully while only the weaker one is lost.

for successful header detection as

$$p(\mathrm{h}=\mathrm{succ}) = \min\{p(\mathrm{h}=\mathrm{succ/coll}), p(\mathrm{h}=\mathrm{succ/inter})\}$$

where $p(\mathrm{h}=\mathrm{succ/coll})$ and $p(\mathrm{h}=\mathrm{succ/inter})$ denote the probabilities for correct header detection under the collision and interference mechanisms, respectively. In contrast to header detection, data detection in RP-CDMA is only a function of the interference resolution capabilities of the data detector with associated probability of correct detection $p(\mathrm{d}=\mathrm{succ/inter})$. Thus, the overall system throughput, S, of an RP-CDMA system can be found as

$$S_{\mathrm{RP-CDMA}} = G \times \min\{p(\mathrm{h}=\mathrm{succ}), p(\mathrm{d}=\mathrm{succ/inter})\}$$

where G denotes offered load in packets. Note that the notion of G directly implies that packets are generated in the transmitters at a rate of $\lambda = 1$ and are transmitted with probability $p(\mathrm{trans}) = 1$. As a result, a load of $G = x$ packets translates directly into x active transmitters out of the overall network population.

A. *The Performance of RP-CDMA and Spread Aloha From an Interference Perspective*

In our model, we assume that all transmitters in the network employ power control, the powers at the receiver are equal for all nodes and the following holds

$$P_{\mathrm{RX,j}} = P_{\mathrm{RX}},\ \forall j,\ j = 1, \ldots, K. \tag{2}$$

1) Performance of Spread Aloha Under Interference Effects: Before addressing RP-CDMA from an interference perspective, we first determine the achievable performance under Spread Aloha. As has been shown in [10]–[12], because of its asynchronous operation and restrictive collision mechanism, Spread Aloha is limited to matched filter detection, and multiuser technology cannot improve its performance. From [13], [14], the received SNIR, Γ, for a packet j with a matched filter receiver is given by

$$\Gamma_j^{(\mathrm{mf})} = \frac{P_j}{\sigma^2 + \frac{1}{N}\sum_{i=1, i\neq j}^{n} P_i} \tag{3}$$

where we assumed n active packets in the system at the time packet j is transmitted.

2) RP-CDMA and Multiuser Interference: Similarly to Spread Aloha, RP-CDMA header detection has to rely on matched filtering. However, because of its packet structure, header detection in RP-CDMA faces interference from header/header (*h/h*) and header/data (*h/d*) overlaps. As a consequence, since interference is dominated by *(h/d)* overlaps, *from an interference perspective*, distributed access control such as carrier sense multiple access with collision avoidance (CSMA/CA) on the header frame, is unlikely to significantly improve system performance.

In addition to perfect power control, we allow the RP-CDMA nodes to increase the header transmission power over the data transmission power to increase the probability for correct header detection. Therefore, to determine the level of multi-access interference, we need to investigate the number of packet overlaps in both virtual channels as a function of $\frac{L_\mathrm{d}}{L_\mathrm{h}}$. For successful header detection, we require that the total interference caused by overlapping *(h/h)* and *(h/d)* portions is less than some threshold γ. We define the two supporting sets: (i) $\mathcal{H}$ = the set of *(h/h)* overlaps, and (ii) $\mathcal{D}$ = the set of *(h/d)* overlaps and accordingly modify (3) as

$$\Gamma_j^{(\mathrm{mf})} = \frac{P_{\mathrm{h,i}}}{\sigma^2 + \frac{1}{N_\mathrm{h}}\sum_{\mathcal{H}} P_{\mathrm{h,k}} + \frac{1}{N_\mathrm{d}}\sum_{\mathcal{D}} P_{\mathrm{d,j}}} \tag{4}$$

where j refers to the packet under observation, P_h and P_d represent the transmission powers of the header and data portions of the packet, respectively. In order to determine performance, we note that the sizes of those sets, $|\cdot|$, given n active packets, can be approximated by

$$|\mathcal{H}| \approx E[\mathrm{h/h}] = n\frac{L_\mathrm{h}}{L_\mathrm{d}} \tag{5}$$

and

$$|\mathcal{D}| \approx E[\mathrm{h/d}] = n\left(1 - \frac{L_\mathrm{h}}{L_\mathrm{d}}\right) \tag{6}$$

Substituting (5) and (6) in (4), and noting that successful detection of the header requires $\Gamma_j^{(\mathrm{mf})} > \gamma$ and drop the user index for simplicity, for the critical number of supportable transmissions, n_{crit}, we get

$$n_{\mathrm{crit}} \leq \frac{\frac{P_h}{\gamma} - \sigma^2}{\frac{P_h L_\mathrm{h}}{N_\mathrm{h} L_\mathrm{d}} + \frac{P_d}{N_\mathrm{d}}\left(1 - \frac{L_\mathrm{h}}{L_\mathrm{d}}\right)} + 1. \tag{7}$$

In Figure 3, we investigate the performance of the header detection process as a function of the spreading gains N_h and N_d, $P_\mathrm{h}/P_\mathrm{d}$ as well as $L_\mathrm{d}/L_\mathrm{h}$. We assume a header length of $L_\mathrm{h} = 50$ bits, which allows for reliable timing recovery [15] as interference increases. Figure 3 (a) presents variations of n_{crit} as $N = N_\mathrm{h} = N_\mathrm{d}$ and $L_\mathrm{d}/L_\mathrm{h}$ vary and $P_\mathrm{h}/\sigma^2 = 15$ dB and $P_\mathrm{d}/\sigma^2 = 10$ dB. We observe that while increasing $N = N_\mathrm{h} = N_\mathrm{d}$ offers a monotonic increase in the number of detected headers, performance increases only slowly when we increase $L_\mathrm{d}/L_\mathrm{h}$ alone. Figure 3 (b) presents similar results when we fix $N = N_\mathrm{h} = N_\mathrm{d} = 20$ and $P_\mathrm{d}/\sigma^2 = 10$ dB and vary P_h/σ^2. Increasing P_h/σ^2 offers a monotonic increase in the number of detected headers while for a given P_h/σ^2 and P_d/σ^2, increasing $L_\mathrm{d}/L_\mathrm{h}$ beyond $L_\mathrm{d}/L_\mathrm{h} \approx 25$ offers little performance gain. Finally, in Figure 3 (c), we observe that for fixed $L_\mathrm{d}/L_\mathrm{h} = 25$ and $P_\mathrm{d}/\sigma^2 = 10$ dB, increasing either or both, P_h and N, improve system performance.

As a result of the discussion in Figure 3, we conclude that there is a point after which RP-CDMA becomes *interference limited* instead of *header collision limited*, and increasing $L_\mathrm{d}/L_\mathrm{h}$ does not improve performance noticably. This point depends on N_h respectively $\frac{L_\mathrm{d} N_\mathrm{d}}{L_\mathrm{h} N_\mathrm{h}}$ and $P_\mathrm{h}/P_\mathrm{d}$. As an example, little performance as a function of $L_\mathrm{d}/L_\mathrm{h}$ can be gained once $L_\mathrm{d}/L_\mathrm{h} > 25$. In such cases, it is beneficial to increase N_h separately from N_d such that a maximum effective ratio of header to data *on the channel* of $N_\mathrm{d} L_\mathrm{d}/L_\mathrm{h} N_\mathrm{h} \approx 25$ is maintained.

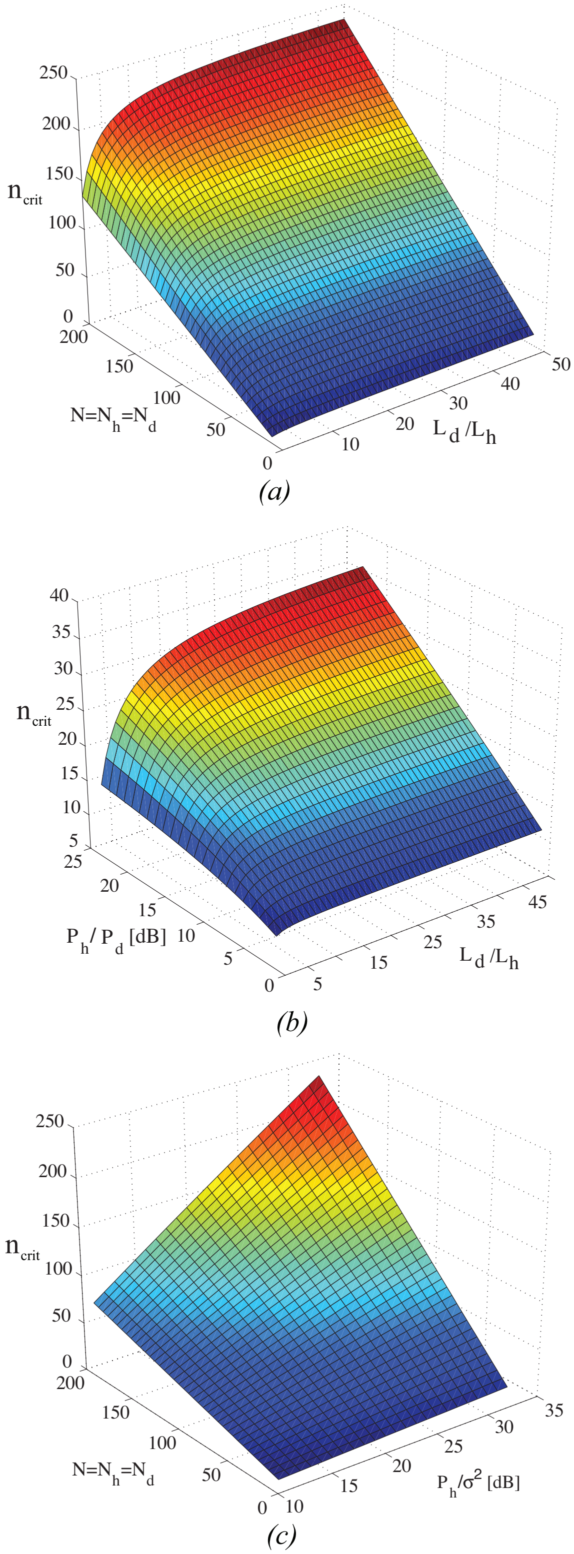

Fig. 3. Performance analysis of RP-CDMA header detection, equal receive powers, interference limit only. In all three plots, $K = 250$. (a), n_{crit} for fixed header and data transmission SNRs of $P_{\mathrm{h}}/\sigma^2 = 15$ dB, $P_{\mathrm{d}}/\sigma^2 = 10$ dB and detection threshold $\gamma = 3$ dB as a function of the header and data spreading gains $N = N_{\mathrm{h}} = N_{\mathrm{d}}$ and the data to header ratio $L_{\mathrm{d}}/L_{\mathrm{h}}$. (b), n_{crit} for fixed $N_{\mathrm{h}} = N_{\mathrm{d}} = 20$ and varying P_{h}/σ^2 for a fixed $P_{\mathrm{d}}/\sigma^2 = 10$ dB. (c), n_{crit} for fixed $L_{\mathrm{d}}/L_{\mathrm{h}} = 25$ and fixed data transmission SNR of $P_{\mathrm{d}}/\sigma^2 = 10$ dB.

IV. The Performance of RP-CDMA Data Detection

In the following, we investigate the performance of data reception with the matched filter, the decorrelator, the MMSE, as well as partitioned spreading demodulation. We proceed to review the performance equations of these four multiuser receivers.

A. Data detection with the Matched Filter

Data detection in RP-CDMA with a matched filter receiver is identical to Spread Aloha, whose performance was evaluated in Section III-A.1.

B. Data Detection with the Decorrelator

The decorrelating receiver inverts the channel to completely eliminate interference. This results in a loss of energy for each user, depending on the user population. Interference no longer depends on the power of other users, and the SNIR for packet j after the decorrelating receiver reduces to SNR [13]

$$\Gamma_j^{(\mathrm{deco})} = \frac{P_j}{\sigma^2}\frac{N - n + 1}{N}. \tag{8}$$

C. Data Detection with the MMSE Filter

The MMSE establishes a filter to minimize the mean square error caused by noise and the multi-access interference. For the MMSE receiver, a given packet j will be received successfully, if its power P_j satisfies [13]

$$\gamma \leq \frac{P_j}{\sigma^2 + \frac{1}{N}\sum_{i=1, i\neq j}^{n} \frac{P_j P_k}{\gamma P_k + P_i}} \tag{9}$$

D. Data Detection with Partitioned Spreading

Partitioned spreading is a recently proposed technique which utilizes the benefits of interleaving and iterative receiver processing, see [14], [16], [17] for more details. In partitioned spreading, the original spreading sequences are separated into several chunks called partitions, and partitions are transmitted separately after passing through an interleaver. The partitions of each data symbol are understood as symbols of a repetition code, and are iteratively decoded at the receiver using message passing or a multistage demodulation. It was shown in [14], [16]–[18], that partitioned spreading exhibits virtually optimal near-far resistance, and the variance evolution at iteration i is given by

$$\begin{aligned} \sigma_i^2 \quad &\leq \quad \sum_{k=1}^{n} \frac{P_k}{N} \times \\ &\min \left(\frac{1}{1 + \frac{M-1}{M}\frac{P_k}{\sigma_{i-1}^2}}, \pi Q\left(\sqrt{\frac{M-1}{M}\frac{P_k}{\sigma_{i-1}^2}}\right)\right) + \sigma^2 \end{aligned} \tag{10}$$

where the summation is over all active users and M denotes the number of partitions. A packet j will be successfully decoded if after iteration i its SNIR satisfies

$$\Gamma_j^{(\mathrm{ps})} = \frac{P_j}{\sigma_i^2} \geq \gamma.$$

V. Network Simulations

We now simulate the throughput of RP-CDMA in a base station centric network with the various detectors introduced above. Again, our base line for comparison is Spread Aloha. From Section III, we imagine and anticipate that the performance of RP-CDMA – especially when partitioned spreading detection is applied to the data frame – is critically determined by the interference suppression capabilities of the header detection stage rather than by the header collision process.

A. Simulation Results of Base Station Centric Networks

We assume that the accessing terminals reside within a cell and transmit packets to a central base station. Packets are generated and transmitted according to Section II-C. Packet transmission occurs asynchronously and to determine the distribution of $L_\mathrm{d}/L_\mathrm{h}$, we turn our attention to Internet2 traffic. There, the packet size is trimodally distributed with lengths of $L = 50$, $L = 500$, and $L = 1500$ bytes and respective probabilities of occurrence of $p(\mathrm{L}=50) = 0.5$, $p(\mathrm{L}=500) = 0.4$, $p(\mathrm{L}=1500) = 0.1$ [19]. Thus, with a header length of $L_\mathrm{h} = 50$ bits, we have $\mathrm{E}[L_\mathrm{d}/L_\mathrm{h}] = 60$. Clearly, with these figures and from a mere collision perspective, RP-CDMA promises great improvements over Spread Aloha, possibly approaching the performance of a fully access controlled system, as was also concluded in [6], [20], [21]. In our model, we assume that transmission rates have been assigned, such that any packet that exceeds the detection thresholds will be decoded respectively detected successfully.

We first compare the throughput with Spread Aloha to the achievable performance under RP-CDMA. Figure 4 shows simulation results in the case when the header and data SNRs are $P_\mathrm{h}/\sigma^2 = 15$ dB and $P_\mathrm{d}/\sigma^2 = P_\mathrm{SA}/\sigma^2 = 12$ dB, resulting in $P_\mathrm{h}/P_\mathrm{d} = 3$ dB. Furthermore, the header and data spreading gains are $N_\mathrm{h} = N_\mathrm{d} = N_\mathrm{SA} = 20$ and we have a data detection threshold of $\gamma_\mathrm{d} = \gamma_\mathrm{SA} = 3$ dB. For data detection, we employ all multiuser detectors discussed in Section III. For header detection, we assume a threshold for matched filtering of $\gamma_\mathrm{h} = 1$ dB. Choosing a lower threshold is possible in RP-CDMA, since the header is merely used for timing and code-ID recovery with resulting low transmission rates. While the value of 1 dB has been chosen somewhat arbitrarily, we note that even lower values might be possible in practice, see [22] for a discussion on the fundamental limits of detection in the low-SNR regime. Starting with Spread Aloha, we see that throughput immediately diverges significantly from the optimal $S = G$ curve as $G > 0$ and achieves a low maximum of $S_\mathrm{SA} \approx 4.3$ at $G = 8$. Somewhat similar to this, the RP-CDMA header process is also unable to follow the optimal $S = G$ curve as the load increases. However, even at a load of $G = 40$ packets, the throughput in the (virtual) header channel diverges only marginally from optimal behavior. Hence, the remaining question to be answered is what fraction of this performance can be harnessed by the RP-CDMA data detection stage. Proceeding from lowest to highest performance, we have the matched filter followed by decorrelation detection, collapsing at a load of $G = 18$ transmitters. This is easily exceeded with the MMSE, where the supportable number of transmissions equals $G = 27$ packets. Even higher performance can be achieved with partitioned spreading demodulation, where the maximum load approaches $G = 34$, in unison with [16]–[18]. For all the receivers, the throughput curves break down rapidly,

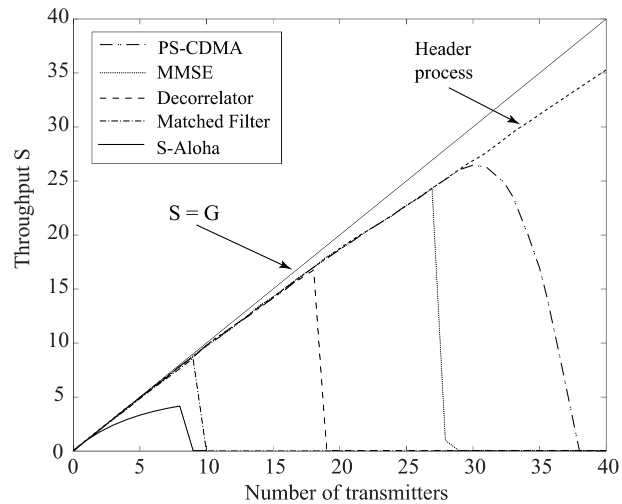

Fig. 4. Network throughput as a function of the network load, G. $N_\mathrm{h} = N_\mathrm{d} = N_\mathrm{SA} = 20$, trimodal packet sizes and $L_\mathrm{h} = 50$ bits such that $\mathrm{E}[L_\mathrm{d}/L_\mathrm{h}] = 60$. $P_\mathrm{d}/\sigma^2 = P_\mathrm{SA}/\sigma^2 = 12$ dB, $P_\mathrm{h}/\sigma^2 = 15$ dB. Detection thresholds of $\gamma_\mathrm{d} = 3$ dB, $\gamma_\mathrm{h} = 1$ dB. For partitioned spreading, $M = N_\mathrm{d}/2 = 10$.

indicating that after a certain load, the effective SNIR after the detector was not sufficient for detection.

Furthermore, although it seems that the benefit in upgrading from MMSE detection to partitioned spreading demodulation in terms of additional load is relatively small (7 more users), in reality, this is only part of the picture. It was shown in [16]–[18], that in contrast to other receiver methodologies, partitioned spreading allows to resolve virtually all multiuser interference. In our model, the throughput regions for the various demodulators are formed by the packets whose SNIR after the demodulator satisfy $\Gamma_i > \gamma$; our model does not capture the degree to which the SNIRs exceed the detection threshold. In short, since the per-user SNR is higher with partitioned spreading demodulation, it allows for *higher data rates* and therefore higher spectral efficiency. Another perspective on this issue is that for a targeted data rate, partitioned spreading demodulation allows to transmit the data frame at a lower SNR, therefore making it possible to increase $P_\mathrm{h}/P_\mathrm{d}$ which improves the performance in the header channel. As we have seen in Section III, the behavior of the header process is non-linear in some parameters and improving its performance directly faces limitations. Along these lines, upgrading RP-CDMA to partitioned spreading demodulation might be the easier and more practical way to improve performance.

VI. Conclusions

We revisited RP-CDMA and discussed its system performance. In contrast to previous works, our investigations were based on a realistic Spread Aloha process for header transmission. While earlier results suggested that RP-CDMA throughput is only limited by the capabilities of the base station receiver as $L_\mathrm{d}/L_\mathrm{h}$ increases, we showed that with a realistic model which takes multiuser interference into account, harnessing the benefit of increased $L_\mathrm{d}/L_\mathrm{h}$ goes along with a necessary increase in $P_\mathrm{h}/P_\mathrm{d}$ and/or N_h and N_d. Essentially, there is a point after which the RP-CDMA header process becomes *interference limited* instead of *header collision limited*, and increasing $L_\mathrm{d}/L_\mathrm{h}$ does not noticably improve overall performance. This point depends on N_h respectively $\frac{L_\mathrm{d} N_\mathrm{d}}{L_\mathrm{h} N_\mathrm{h}}$ and $P_\mathrm{h}/P_\mathrm{d}$.

For the analysis of RP-CDMA *payload detection*, we compared the performance of partitioned spreading to the matched filter, the decorrelator and the MMSE filter. As expected, partitioned spreading greatly outperforms other reception methodologies, lead by the MMSE, the decorrelator and finally the matched filter receiver.

We simulated the throughput of an RP-CDMA network and compared it to Spread Aloha in a base station centric environment. We pointed out that because of the vastly superior interference resolution capabilities of partitioned spreading, in all cases, much higher *data rates* can be used – thus improving system performance. From another angle, for a targeted data rate, partitioned spreading demodulation allows to transmit the data frame at a lower P_d, therefore increasing $P_\mathrm{h}/P_\mathrm{d}$ which improves the performance in the header channel. This is especially important, since increasing the performance in the header channel *directly* may not always be practical due to the scarce wireless resource but also limitations on transmission power.

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