

# *A Power Dissipation Comparison of the R-TDMA and the Slotted-Aloha Wireless MAC Protocols*

George R.J. Linnenbank  
University of Twente, Department of Computer Science  
P.O.Box 217, 7500 AE Enschede, the Netherlands  
linnenba@cs.utwente.nl

## **Abstract**

In this paper two wireless multiple-access protocols are compared by their power dissipation for the uplink traffic of a wireless networks. After briefly discussing the behaviour of the Slotted Aloha protocol (Abramson, 1985) and the R-TDMA protocol (Linnenbank, 1995), we estimate the energy that is dissipated by the protocols to transmit a packet. We will show that for general loads, the power dissipation of the R-TDMA protocol is far less than that of the Slotted Aloha protocol.

## **1 Introduction**

In recent years more and more mobile wireless equipment is being used. Starting with the mobile wireless telephone and followed by the portable computer, emphasis is made on miniaturizing components to make devices lighter. One of the bottlenecks appears to be the battery that provides the device with energy. The amount of energy stored in the battery must be sufficient to make it worthwhile to carry a mobile communication device with you. However, the smaller the device, the smaller the battery. Therefore, less energy can be provided. Power management is one of the research areas of the Moby Dick project (Mullender, 1995). In this project several research fields are covered: security, network architecture, data consistency, environment awareness and power management. In this paper we focus on the power management.

Research is focusing on power-efficient components and power-efficient algorithms to expand the time that a wireless device can be used. Using low-power components is one approach that helps to save scarce battery energy. Reducing the overhead of the multiple-access protocol is another way to reduce energy consumption.

In this paper we will investigate the power dissipation of two multiple-access protocols: the Slotted Aloha protocol and the R-TDMA protocol. For each multiple-access protocol we briefly describe the model of the protocol and then we analyse the power dissipation of that protocol. Finally, we will compare the results and draw some conclusions.

To obtain sensible results, it is necessary to fill in some properties and parameters of the wireless system. We have made the following assumptions:

- The accuracy of the clock crystals is assumed to be perfect.
- The channel bit rate is 1Mbps and the channel is assumed to be perfect (No noise present).
- A data message is an ATM cell of 53 bytes or 424 bits long.
- The activation time of the transmitter or receiver is neglected.
- A single frequency channel is used.
- The receiver and transmitter are switched off as much as possible to save energy.
- We assume<sup>1</sup> that the transmitter consumes 10W and the receiver 1W.
- Analyses are made from the view point of a single station.

## 2 Slotted Aloha

In Slotted Aloha, time is divided into slots (Abramson, 1985). We use a slotsize such that a data message and its associated acknowledgement fit in a slot. Since mobile stations need to know that they are in a cell of a base station, the base station sends identification messages regularly. These messages can be sent in a time slot that has not been used for a data transmission by a mobile station. I.e. the base station does not detect a carrier signal in the beginning of a slot. When the base station sends an identification message in every free slot, then a mobile station can detect a base station very fast (within a free slot time) and synchronise to that base station.

Each slot is accessed with probability  $p$  by each mobile station. The aggregated load  $G = n * p$ , where  $n$  is the number of mobile stations. When the same assumptions are made that are often found in the literature, i.e. the aggregate network load does not change when a single station goes in back-off (asymptotically true for an infinite number of stations generating the aggregate load  $G$ ), then we can state that whether or not backoff is used, the probability of success of each data transmission does not change. The number of transmission attempts needed to send a data message remains unchanged but is only spread over a longer time period when back-off is used. Therefore, a backoff procedure is of no concern in the analysis of power dissipation.

The Slotted Aloha protocol timing is as follows:

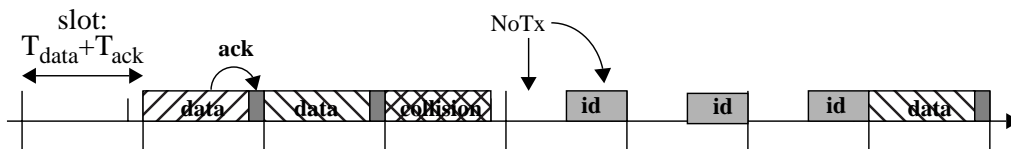


Figure 1. Slotted Aloha protocol timing

- An acknowledgement is  $1/8 * 424 = 53$  bits large or  $53 \mu s$  long.
- An identification message is  $1/2 * 424 = 212$  bits large or  $212 \mu s$  long.
- A slot contains room for a data message and its associated acknowledgement and is  $424 + 53 = 477$  bit times or  $477 \mu s$  long.

1. In near-field radio experiments, the power dissipation was determined to be 10.0W for the transmitter and 1.0W for the receiver. During these experiments, no optimizations were made to make the transmitter or receiver more power efficient. These measurements are indicative for dissipation comparison of protocols. The analysis that we give is general and when more efficient dissipation figures are determined, these can easily be substituted in the equations.

## 2.1 Transmission dissipation

The energy dissipated through transmission is determined by the time that the transmitter has been transmitting. When a wireless station sends a message, the probability that it is successfully received at the base station is given by the formula

$$P(succ) = (1-p)^{n-1} \quad (\text{EQ 1})$$

Where  $n$  is the number of active stations and  $p$  is the probability that a station sends a message in a slot. Then the average number of transmissions  $\nu$  needed to send a message successfully is given by

$$\nu = \frac{1}{(1-p)^{n-1}} = (1-p)^{1-n} \quad (\text{EQ 2})$$

For a single mobile station ( $n=1$ ),  $\nu=1$  for all access probabilities  $p$ . Thus there is no transmission overhead in the case that there is only a single mobile station. Transmission overhead only occurs when there are more than one mobile stations. Using  $\nu$  the average time  $T_{Tx}$  that the transmitter is active per packet is easily determined to be

$$T_{Tx} = \nu \cdot T_{data} \quad (\text{EQ 3})$$

## 2.2 Reception

The receiver of a mobile station must be on in order to receive the identification message of a base station for base station detection and for time synchronisation. Also it must be on to receive possible acknowledgements after attempting to transmit a data message. We assume that a mobile station waits for an identification message only once. Therefore, the power dissipated to receive an identification message can be neglected.

Every time the mobile station attempts to send a data message, the receiver of the mobile station is switched on to see if an acknowledgement is transmitted by the base station. After the time it requires to receive an acknowledgement ( $T_{ack}$ ), the receiver is switched off until another data transmission attempt is made. Since the average number of transmissions attempts to send a single data message is known to be  $\nu$ , the time  $T_{RxOn}$  per packet that the receiver is switched on in order to detect an acknowledgement is given by

$$T_{RxOn} = \nu \cdot T_{ack} \quad (\text{EQ 4})$$

However, only the last of the  $\nu$  transmission attempts was successful. Only after that data transmission, the receiver successfully receives an acknowledgement. Therefore, the time per packet that a station is really receiving acknowledgements ( $T_{Rx}$ ) is

$$T_{Rx} = T_{ack} \quad (\text{EQ 5})$$

Thus  $T_{Rx}$  is a constant with the value  $53\mu\text{s}$ .

## 2.3 Dissipation

The total dissipation (measured in Watts or Joules) is given by the time that the transmitter is on, the receiver is on and the receiver is receiving a message, multiplied by the power dissipations of each of these functions. The total energy dissipation per packet  $P_{total}$  is given by

$$P_{total} = T_{Tx} \cdot P_{Tx} + T_{RxOn} \cdot P_{RxOn} + T_{Rx} \cdot P_{Rx} \quad (\text{EQ 6})$$

Since the processing of the actually received information can be performed using low power components (in the order of microwatts), we can neglect  $P_{Rx}$ . We apply the measured values to the formula of  $P_{total}$  giving the graphs in Figure 2.

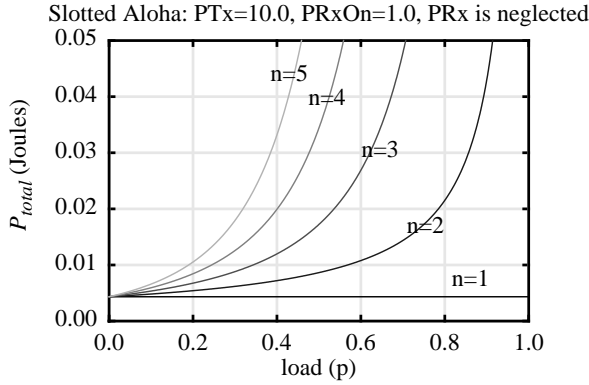


Figure 2. Slotted Aloha power dissipation per packet for 1..5 stations

## 3 Request-TDMA

In the R-TDMA protocol (Linnenbank, 1995), time is divided into fixed size frames. A *frame* contains  $S$  time slots for communication. The frame structure is shown in Figure 3. There are two special slot types in each frame, the *Clear To Send* (CTS) and the *Request To Send* (RTS) slots. The first slot in the frame is the CTS slot. The base station uses this slot to inform the mobile stations to which connections the data slots are allocated in the *current frame*. Somewhere in the frame is the RTS slot, where mobile stations can use minislots to request data slots for the *next frame*. The remaining  $S-2=D$  slots are the *data slots* which can be used for data communication.

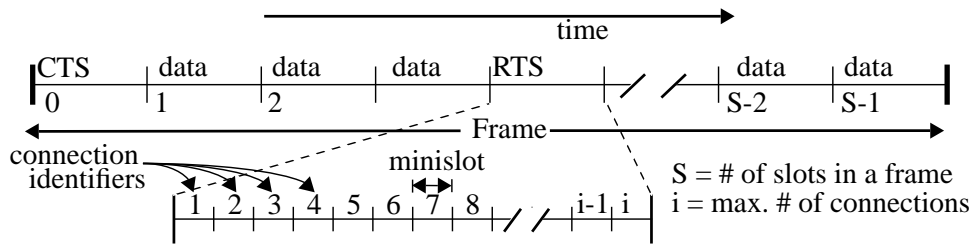


Figure 3. The R-TDMA frame structure

The timing used in the following analysis is as follows:

- $T_{slot} = T_{data} = T_{CTS} = 53 \cdot 8 = 424 \mu s$
- $T_{RTS} = 3 \cdot 8 = 24 \mu s$  (17 minislots fit in a slot)
- $T_{frame} = S \cdot T_{slot} = 20 \cdot 424 = 8480 \mu s = 8.48ms$

Since connections are set up only once at the start of a communication session, their contribution to the average energy dissipation per packet is neglectable. Therefore the connection setups are not included in the analysis.

### 3.1 Transmission dissipation

When the packet generation rate is  $p$  packets per slot, and the frame size is  $S$ , then the average number of packets generated per frame is  $pS$ . We assume that an RTS is only transmitted when a station has data to transmit. As the probability that a packet is generated is  $p$  per slottime, the probability that no packets are created in a frame is  $(1-p)^S$ . Thus the probability  $P(RTS)$  that an RTS is transmitted is  $P(RTS)=1-(1-p)^S$ .

Per frame  $pS \cdot T_{data} + P(RTS) \cdot T_{RTS}$  time is used for transmission on average. Since there are  $pS$  packets per frame, the transmission time  $T_{Tx}$  per packet is

$$T_{Tx} = \frac{pS \cdot T_{data} + P(RTS) T_{RTS}}{pS} = T_{data} + \frac{P(RTS) T_{RTS}}{pS} \quad (\text{EQ 7})$$

As we assume that the channel is perfect and no collisions occur due to the contentionless protocol, this is all the time that energy is used for transmission. The transmission overhead in time per packet is given by  $P(RTS) \cdot T_{RTS} / (pS)$ . This overhead has a maximum of  $T_{RTS}$  per packet for  $p=0$  and decreases fast for higher loads.

### 3.2 Reception

In a frame the CTS needs to be received to determine the slot allocation in the current frame. However, when no RTS was transmitted, there is no need to receive the CTS message and the receiver can be left switched-off. Therefore, the probability  $P(CTS)$  that an CTS needs to be received is equal to the probability that an RTS was transmitted. Thus  $P(CTS)=P(RTS)$ . On average  $P(CTS) \cdot T_{data}$  seconds is spent receiving per frame. Put against the number of packets per frame ( $pS$ ), the reception overhead becomes  $P(CTS) \cdot T_{data} / (pS)$  per packet. Expressing the reception overhead  $T_{RxOn}$  in time per packet is given by

$$T_{RxOn} = \frac{P(CTS) T_{data}}{pS} \quad (\text{EQ 8})$$

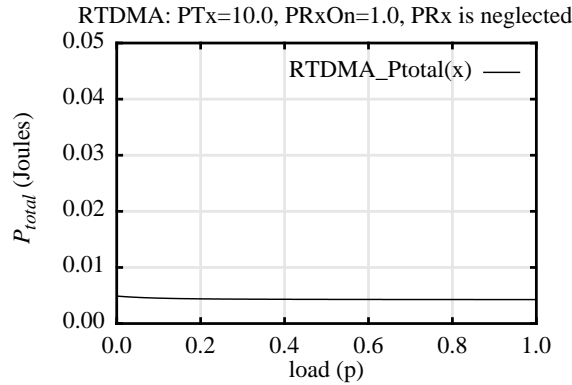
Again the overhead has a maximum for low values of  $p$ . The maximum reception overhead is  $T_{data}$  for  $p=0$  and decreases fast for higher values of  $p$ .

### 3.3 Total dissipation

Again assuming that  $P_{Rx}$  is outweighed by  $P_{RxOn}$  by using very low-power processing components, the total dissipation  $P_{total}$  per packet is given by the sum of the transmitter dissipation per packet and the receiver dissipation per packet.

$$P_{total} = P_{Tx} \cdot T_{Tx} + P_{RxOn} \cdot T_{RxOn} \quad (\text{EQ 9})$$

Applying the same values for transmission and reception dissipation as in Figure 2 (10W for transmission and 1W for reception), the following power dissipation graph is obtained



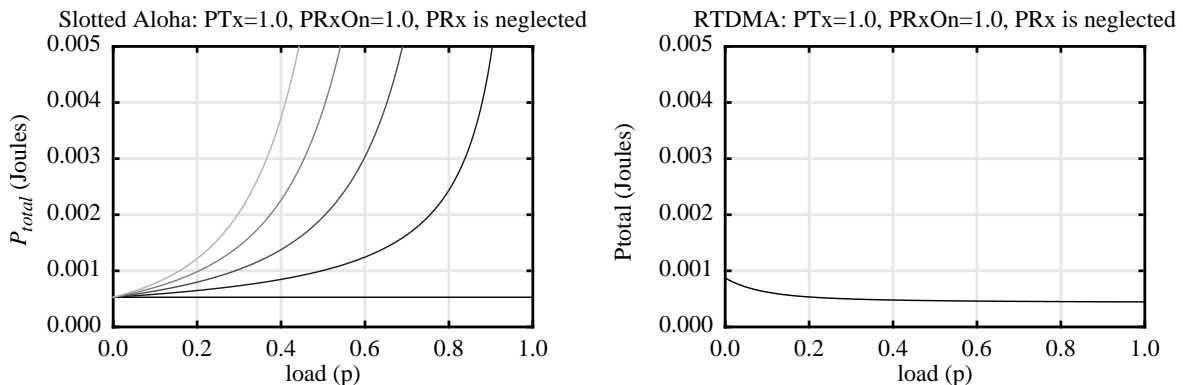
**Figure 4. R-TDMA power dissipation per packet**

Note that it takes  $424.0/10^6$  seconds to send a single packet, thus the optimal dissipation per packet would be transmitting that packet only which gives  $10W * 424.0/10^6s = 0.00424J$  per packet in the 10W transmitter and 1W receiver dissipation case. The graph shows that for all loads the dissipation is close to this optimum.

## 4 Conclusion

First of all we conclude that for the R-TDMA case, the power dissipation is independent of the activity of other users, where in the Slotted Aloha case the power dissipation depends strongly on the activity of other users. Assuming that the network is not saturated, the performance of R-TDMA is also independent of the number of users. In the Slotted Aloha case the number of users that generate a certain load influences the performance.

Comparing the R-TDMA protocol to the Slotted Aloha protocol shows that the power efficiency is much better in the R-TDMA case. The overhead in R-TDMA is only relatively high under very low loads while the overhead of Slotted Aloha is ever increasing with higher loads (except for the optimal situation with 1 mobile station). Estimating the power dissipation when setting  $P_{Tx}$  and  $P_{Rx}$  both to 1W gives similar results.



**Figure 5. Power dissipation per packet for equal receiver and transmitter dissipation**

From the analyses we can conclude that R-TDMA outperforms Slotted Aloha under all but the lowest loads, except for the single user situation. In that case Slotted Aloha has the better performance.

## 5 References

- (Abramson, 1985)** Abramson, N., Development of the ALOHANET, IEEE Transactions on Information Theory, vol. IT-31, pp. 119-123, March 1985.
- (Linnenbank, 1995)** Linnenbank, G.R.J., et al., *Request-TDMA: A Multiple-Access Protocol for Wireless Multimedia Networks*, Proceedings IEEE Third Symposium on Communications and Vehicular Technology in the Benelux, Eindhoven, The Netherlands, 1995.
- (Mullender, 1995)** Mullender, S.J, Corsini, P., Hartvigsen, G., Moby Dick - The Mobile Digital Companion, LTR 20422, Annex I - Project Programme, December 1995.