Performance analysis of broadcast in mobile ad hoc networks with synchronized and non-synchronized reception

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Abstract

Analyzing the performance of broadcast in mobile ad hoc networks is necessary because of the importance of broadcast in multiuser communications and the characteristic difference between wireless communications and wired communications. If the time lag between collided packets is small on the order of a symbol, the reception is *synchronized*; otherwise, the reception is *non-synchronized*. We find that there is a time complexity gap exponential with the degree of the network between the performance of synchronized and non-synchronized reception. Besides, we also take into account the possibility that a processor is busy with other tasks, and we find that allowing the processors to be temporarily busy with other tasks will not degrade the performance significantly. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

Broadcast, i.e. sending a message initiated from a user to other users in the network, is an important task in distributed systems and mobile networks. It can be used for disseminating information among a set of receivers [1] and exchanging messages in distributed computing [2]. Applications of broadcast include sending control messages to all users and video conferencing [1].

In single-hop wireless networks with a base station, such as cellular networks, broadcast can be done by sending the message via the base station to every mobile user in the downlink channel [3]. However, in a mobile ad hoc network [4], there is not a base station that can communicate with all users directly, and not all users can receive the messages from all other users directly [2]. Therefore, ad hoc mobile networks belong to multihop networks, in which it is not so simple to solve the broadcast problem. Modern applications of multihop mobile networks are given in Refs. [5–8], such as disaster recovery, e.g. search and rescue in fire or earthquake. Another example [5–8] is ad hoc personal communications networks, which could be rapidly implemented, for example, on a campus, to support collaborative computing and provide access to the Internet during special events like concerts and festivals.

Numerous researches have been conducted to investigate the broadcast problem in multihop wireless network. Chlamtac and Weistein proposed a centralized broadcast algorithm with time complexity $O(R \log^2 V)$, where R is the radius of the network, i.e. the maximum number of edges in the shortest path between two nodes, and V is the number of mobile users in the network [9]. Broadcast protocol based on multi-cluster architecture [10] was proposed in Ref. [11]. In Ref. [12], it was proved that any broadcast algorithm requires $\Omega(\log^2 V)$ time slots to finish for a network with radius equal to two. In Ref. [13], it was proved that any distributed broadcast algorithm requires $\Omega(R \log V)$ time slots to finish. Bar-Yehuda et al. in Ref. [14] proposed a distributed randomized algorithm, which needs only $O((R + \log V/\epsilon)\log V)$ time slots to finish with probability $1 - \epsilon$. This algorithm is exponentially superior to any distributed deterministic algorithm, which takes $\Theta(V)$ time slots even for a radius-3 network. Based on this randomized algorithm, a routing and multiple broadcast algorithm was proposed in Ref. [15]. In Ref. [16], a $\Omega(D \log(V/R))$ lower bound for randomized broadcast algorithm was provided by Kushilevitz and Mansour.

In previous researches such as Refs. [9–16], it was often assumed that the reception of a packet is always successful when there is only one packet received, and it always fails when more than one packet are received at the same time. In a real wireless channel, even if there is only one packet

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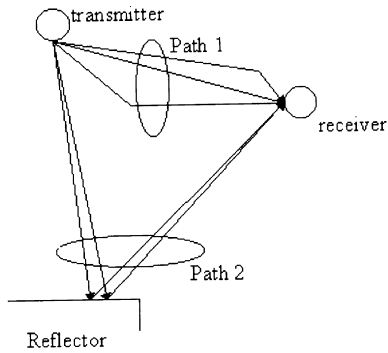*E-mail address:* kpan@orchid.ee.ntu.edu.tw (K.-H. Pan).

Fig. 1. Illustration of the physical layer multipath and propagation delay.

transmitted, it is possible that this packet is not acquired successfully. When there are more than one packet received, it is possible that a packet is acquired successfully [15]. Therefore, in the previous work [17], we analyzed the performance of a distributed randomized broadcast algorithm with consideration of channel reliability. The analysis shows that the performance of randomized broadcast algorithm is satisfactory with channel reliability. Furthermore, adjusting the retransmission probability is a good way to obtain better performance [17].

However, power level is only one of the several important issues in wireless networks. For example, another critical issue is the timing of the signals. Therefore, in this paper, we analyze the performance of broadcast with more considerations than those in Ref. [17]. The impact of the time lag at *symbol (bit)* level *between collided packets* is analyzed. If the time lag between packets is small, we say the reception is *synchronized*. If the time lag is large, we say the reception is *non-synchronized*. To correctly obtain the information from the signal, the receiver has to know when the signal starts and ends. Therefore, investigating these timing issues will be very important to the performance of wireless networks.

Related research topics appear in the analysis of single-hop networks. The phenomenon that a collision does not necessarily destroy packets is called capture [2,18,19]. Capture could enhance the performance of random access protocol radio such as ALOHA, and capture influences the performance of CDMA (code division multiple access) [19]. The goal of the MAC (medium access control) in those topics is to achieve multiple access. Therefore, the packets involved in a collision have different contents. The broadcast problem here contains only single message; therefore, it is successful as long as at least one packet is received successfully. Thus, the MAC is utilized to carry this packet to all users. Besides, there can be more than one hop in the network, so the packet has to be transmitted hop by hop to reach every user. Therefore, the packets involved in a collision have the same contents, if the packets are broadcast in ordered sequence.

Furthermore, the probability that a processor is so busy with other tasks that temporarily does not execute

the broadcast algorithm is included. This may result from some emergency event that a processor has to deal with, or power-saving considerations, etc. In another point of view, allowing a processor to be busy with other things also gives the processor more freedom since it can deal with other important jobs. Thus, it would be desired to analyze the performance of allowing a processor to be busy with other things and temporarily not carrying out the algorithm.

In this paper we analyze the performance of broadcast with synchronized and non-synchronized reception in mobile ad hoc networks. We examine the performance gap between them. How to adjust the parameters in the broadcast algorithm to achieve better performance is also investigated. The rest of the paper is organized as follows. Section 2 analyzes the probability of successful reception of a packet. Performance of broadcast algorithms is analyzed in Section 3. Section 4 gives numerical examples and discussions. Conclusions are provided in Section 5.

2. Probabilities of successful reception

This paper takes into account the influence of multipath fading [19]. Fading is used to describe the fluctuation of a signal over a period [19]. The cause of physical-layer multipath is illustrated in Fig. 1, where there are many possible paths for the signal to propagate from the transmitter to receiver, and the propagation length of each path is quite likely to be different. In this paper, it is assumed that the time lag between components from the paths is within a symbol interval, and the sum of their amplitude is Rayleigh distributed [19]. Rayleigh distribution is often used to model the statistical characteristics of the received envelope of a signal transmitted through many paths. The pdf (probability density function) of the signal voltage r with Rayleigh fading is

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} \exp\left(-\dfrac{r^2}{2\sigma^2}\right) & \text{for } 0 \leq r \leq \infty, \\ 0 & \text{for } r < 0, \end{cases}$$

where σ is the rms (root-mean square) value of the received signal voltage, σ^2 is the time-average power of the received signal.

Equivalently, the power level $S = r^2$ is exponentially distributed [19–21]

$$p(S) = \frac{1}{2\sigma^2} \exp\left(-\frac{S}{2\sigma^2}\right).$$

A digital modulator transforms discrete inputs into the continuous waveform at a suitable frequency, and the corresponding demodulator transforms the continuous waveform back to discrete outputs. In this paper, incoherent binary FSK is used for modulation and demodulation. BFSK