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Study of Mobility Effect on Ad-Hoc 802.11b Networks with Automatic Rate Fallback in Impulse Noise Channels

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***Abstract*—In this paper, we study the mobility effect on the throughput of IEEE 802.11 ad hoc mode with automatic rate fallback (ARF) over fading channels with impulse noise. We consider two cases: 1) the system with ARF algorithm and 2) the system with fixed rate. The simulation results show that the proposed system with ARF algorithm adapts to the channel conditions and remains near the top in terms of throughput. In addition, we consider that mobility effect on the throughput. The simulation results show that the throughput is worse when the velocity range is larger.**

Keywords—IEEE 802.11; Automatic rate fallback (ARF) algorithm; Impulse noise; Ad hoc on demand distance vector (AODV) routing

I. INTRODUCTION

The physical layer (PHY) of the IEEE 802.11 supports multiple transmission rates by using different modulation schemes, e.g., the 802.11b supports four PHY rates (1, 2, 5.5 and 11 Mbps) [1]. To achieve the best performance, wireless stations will perform rate adaptation by which each station adaptively selects the best PHY rate depending on its channel quality [2]. Although rate adaptation is unspecified by the 802.11 standards, it plays an important role with respect to the system performance of 802.11 WLANs [3].

The automatic rate fallback (ARF) algorithm is a simple rate adaptation algorithm [4]. ARF estimates a channel quality based on the results of the past transmission attempts, i.e., a certain number of consecutive transmission successes (failures) infer an improved (degraded) channel quality. According to the estimated channel quality, it changes the rate to the next higher or lower one. Due to its simple behavior and wide acceptance in the market, ARF became the basis of many other proposals for rate adaptation algorithms [2] [5] [6] [7] [8] [9]. In [2] [7] [8], the 802.11 WLANs are composed of multiple stations with random locations at a fixed mobile velocity and an access point (AP) with fixed location, called infrastructure networks. However, when stations exceed the AP radio coverage, it is necessary to use another form of WLANs, called ad hoc networks (details in Chapter 2) [5] [6] [9]. In [5] [6] [9], the WLANs consist of stations moving at a fixed mobile speed.

Due to a free communication in ad hoc networks, when stations are in motion, they produce a Doppler shift on those multipath waves resulting in small-scale fading [11]. Consequently, the received signal strength becomes time varying [2] [5] [6] [7] [8] [9]. The Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of a signal under small-scale fading [11]. Such a time varying nature of small-scale fading is closely related to the rate adaptation algorithms. Because a rate adaptation algorithm exploits the past statistics of channel estimation results (e.g., ARF), so it is critical to take into account small-scale fading when evaluating the performance of rate adaptation in WLANs.

The impulse noise usually appears in wireless and PLC networks [12] [13]. Aforementioned researches are not considering impulse noise and stations are in motion at fixed rate [2] [5] [6] [7] [8] [9]. In this paper, we exploit an impulse noise mathematical model and ARF algorithm in ad hoc networks with mobile stations which have random mobile speed and no directional restrictions under time varying Rayleigh channel.

The rest of this paper is organized as follows: In Section 2, we briefly review the IEEE 802.11 WLANs and ad hoc on demand distance vector (AODV) routing protocol. In Section 3, we discuss the channel models including path loss, fading effects and impulse noise, and analyze the bit-error rate (BER) and ARF algorithm. In Section 4, we simulate the throughput of ad hoc networks of the IEEE 802.11b under the DCF mode with ARF algorithm. We conclude this paper in Section 5.

II. BACKGROUND

A. *IEEE 802.11 WLANs*

The IEEE 802.11 standard defines a mandatory medium access control (MAC), called Distributed Coordination Function (DCF) which uses carrier sense multiple access with collision avoidance (CSMA/CA) to reduce the collision probability between multiple stations accessing the medium. The DCF is suitable for ad hoc networks where no coordination point exists [1].

In DCF, an attempting station senses the channel first. If it is still idle after a Distributed Inter-Frame Space (DIFS) period, the station will wait for its random contention window (CW) slot times of idle medium and then transmit. If the packet is correctly received, the receiver will send an ACK frame after a Short Inter-Frame Space (SIFS) period. However, if this packet is not received by the transmitter, an occurring of collision or error will be considered. In this case, the transmitter expends CW size and then waits for a DIFS period and random CW slot times of idle medium. If the channel is still free, it will send the packet again.

In addition, the DCF defines the Request-To-Send (RTS) / Clear-To-Send (CTS) mechanism required the exchange of short RTS and CTS control frames between transmitter and receiver prior to the actual data frame transmission. The details are described in [1] and Fig.1 illustrates the RTS/CTS/data/ACK procedure.

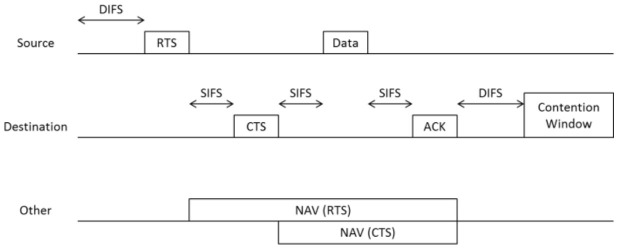

Fig. 1. RTS/CTS/data/ACK procedure

B. *AODV Routing Protocol*

Ad hoc network's main advantage is to provide a free communication. In ad hoc networks, stations need to cooperate with each other in establishing transmission paths. Network topology can rapidly change when stations move. Therefore, it is very possible that packets must be forwarded through different paths every time. Ad hoc routing protocols are used to discover routes between source and destination.

There are different approaches for route discovery in on demand algorithms. Ad hoc on demand distance vector (AODV) routing is one among them. AODV relies on per-station sequence number (SN) for ensuring selection of the most recent routing path [10]. AODV stations maintain a route table which stores routing information of next-hop for destination. For starting route discovery, the source generates a Route-Request (RREQ) packet containing the source's IP address, the last known SN, the destination's IP address and current SN. After generating the RREQ packet, the source broadcasts this one to its neighbors. When a neighboring station receives a RREQ, it creates a reverse route to the source node. Then, the RREQ fills the network to search a route for the destination. The reverse route as created above is used to send a Route-Reply (RREP) packet hop by hop back to the source. Once the source receives the RREP, it can use the path to start the data transmission.

AODV routing protocol contains a number of optional features. When any break of an active path occurs, the station upstream of the break, then creates and broadcasts a Route-Error (RERR) packet to its neighbors. The propagation of the RREQ is controlled by modifying the time to live (TTL) field value of the packet.

AODV doesn't periodically broadcast update information of network topology in the entire network. Only when a data arrives from upper layer and it needs a route for the destination.

III. SYSTEM MODEL AND ARFALGORITHM

A. *Impulse Noise Channel Model*

Impulse noise is a type of electronic noise that occurs in semiconductors. In [14], that the author refers to Markov Gaussian channel model depending on the channel states provides a simple way to describe the burst nature of channel. We assume that the received signal y can be written as

$$y = x + n \quad (1)$$

where$x$ is the transmitted signal with bit energy E_b. $n$is the Gaussian noise depending on the channel state j. $\mathrm{j} = 1$ represents the Gaussian noise only, and $\mathrm{j} = 2$ represents composite noise by the Gaussian and impulse. The probability density functions (PDFs) of n are as follows:

$$\mathrm{p}(\mathrm{n} \mid \mathrm{j} = 1) = \frac{1}{\sqrt{2\pi\sigma^2}} \mathrm{e}^{-\frac{|\mathrm{n}|^2}{2\sigma^2}} \quad (2)$$

$$\mathrm{p}(n \mid j = 2) = \frac{1}{\sqrt{2\pi R\sigma^2}} e^{-\frac{|n|^2}{2R\sigma^2}} \quad (3)$$

whereσ^2 is the Gaussian noise variance, and R is the impulse noise to Gaussian noise ratio. The random variable $n \mid j = 1$ is denoted by $N(0, \sigma^2)$ and $n \mid j = 2$ is denoted by $N(0, R\sigma^2)$.

B. *Log-Distance Path Loss Model with Shadowing*

The Log-distance path loss model is a very popular logarithmic model that is based on a linear dependence between the path loss in decibels and the logarithm of the distance between the transmitter and receiver [11] [15]. This model predicts path loss inside a building or in densely populated areas. The Log-distance path loss model is represented as below:

$$\mathrm{PL}(d)(\mathrm{dB}) = \mathrm{PL}(d_0)(\mathrm{dB}) - 10\alpha \log(d/d_0) + X_\sigma \quad (4)$$

where

$\mathrm{PL}(d)(\mathrm{dB})$is the total measured path loss in decibels at the distance d;

$\mathrm{PL}(d_0)(\mathrm{dB})$is the measured path loss in decibels at the reference distance d_0 from the transmitted signal;

$\alpha$is a path loss exponent depending on the surroundings and building type;

$d$is the distance between the transmitter and receiver in meters;

$d_0$is typically one meter;

$X_\sigma$is a normal random variable in decibels that has zero mean and standard deviation of σ decibels. This model also takes into consideration different obstacles in the transmitter to receiver path. Table 1 lists path loss exponents based on different environments [11].

TABLE I. PATH LOSS EXPONENTS.

Environment	Path Loss Exponent α
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

C. BERs over Rician Fading Channels

In this paper, we consider the Rician fading model in order to simulate the different channel by considering the K-factor which represents the ratio between the line of sight (LOS) power and diffused power.

The IEEE 802.11b standard supports four transmission rates employed different modulation techniques [1]. The differential binary phase shift keying (DBPSK) modulation is used for 1 Mbps and the bit-error rate (BER) over Rician fading channel for DBPSK is given by [16]

$$P_{b,DBPSK+Rician} = \frac{1+K}{2(1+K+\overline{\gamma})} \exp\left(-\frac{K\overline{\gamma}}{1+K+\overline{\gamma}}\right) (5)$$

where$\overline{\gamma}$ is the average SNR.

The differential quadrature phase shift keying (DQPSK) modulation is used for 2 Mbps and the BER over Rician fading channel for DQPSK is given by [16]

$$P_{b,DQPSK+Rician} = \frac{e^{-K}}{2\pi}\int_0^{\pi} \exp[-\frac{K(1+K)}{1+K+\gamma(2-2\sqrt{2}\cos\theta)}] \frac{1+K}{(\sqrt{2}-\cos\theta)[1+K+\overline{\gamma}(2-2\sqrt{2}\cos\theta)]} d\theta (6)$$

The complementary code keying (CCK) modulation is used for 5.5 Mbps and 11 Mbps. The BER considering M-ary bi-orthogonal keying over Rician fading channel for CCK is given by [16]

$$P_{b,CCK+Rician} = \frac{2^{k-1}}{2^{k}-1}\sum_{m=1}^{M-1} \frac{(-1)^{m+1}\binom{M-1}{m}(1+K)}{1+K+m(1+K+\overline{\gamma_S})} \exp\left(-\frac{Km\overline{\gamma_S}}{1+K+m(1+K+\overline{\gamma_S})}\right) (7)$$

where k is $\log_2 M$ and M is 4 or 8 for 5.5 Mbps or 11 Mbps respectively. $\overline{\gamma_S}$is the average symbol SNR which equals to k times of average SNR per bit.

In our paper, two K-factors have been selected; e.g., 0 and 1000. In the case of $K = 0$ (non-LOS propagation path), we simulate a Rayleigh fading channel. If the K equals to or exceeds 1000 (very strong LOS path), it will be very close to an AWGN channel.

A data frame, which is referred to as the Physical Layer Convergence Protocol (PLCP) Protocol Data Unit (PPDU), consists of three parts: PLCP preamble (18 Bytes), PLCP header (6 Bytes) and MAC PDU (MPDU) (30+payload Bytes). The PLCP preamble and the PLCP header are transmitted at the lowest PHY mode, i.e., 1 Mbps, while MPDU is transmitted at the current PHY mode. The packet-error rate can be expressed as [8]

$$P_{e,i} = 1-(1-P_{b,1})^{8\times(18+6)}(1-P_{b,i})^{8(30+payload)}, i \in \{1,2,3,4\} (8)$$

where
$P_{b,1}$is the BER at 1 Mbps, i.e., (3.5);

$P_{b,2}$is the BER at 2 Mbps, i.e., (3.6);

$P_{b,3}$ and$P_{b,4}$ are the BERs at 5.5 Mbps and 11 Mbps respectively, i.e., (3.6) and (3.7).

D. ARF Algorithm

Due to [5] [6], it is not clear that the authors describing ARF algorithm in ad hoc networks, so we redefine the ARF algorithm in this paper. The supported PHY rate set of a station is denoted by $\mathcal{R}$ and each PHY rate is indexed as an integer from 1 to M, i.e., $\mathcal{R} = \{1, 2, 3, \cdots, M\}$, where a larger rate index indicates a higher PHY rate. We denote by r_i, $i \in \mathcal{R}$ the transmission bit rate of ith PHY rate in the rate set. For example, in 802.11b, $\mathcal{R} = \{1,2,3,4\}$ and $M = 4$with $r_1 = 1$ Mbps , $r_2 = 2$ Mbps , $r_3 = 5.5$ Mbps and $r_4 = 1.1$ Mbps. The ARF algorithm is described as below:

- A transmitting station has transmission success count s and transmission failure count f. Upon an AODV routing and a completed RTS/CTS/data/ACK procedure all without transmission failures (e.g. collision, channel error), the station increases s by one and resets f to zero. Otherwise, it resets s to zero and increases f by one.
- Upon S consecutive transmission successes (s = S), a station increases its rate to the next higher one.
- Upon F consecutive transmission failures (f = F), a station decreases its rate to the next lower one.
- Each rate change accompanies count reset, i.e., s = 0 and f = 0.

The flow chart of ARF algorithm is described in Fig.2. Firstly, a station establishes the route between the source and the destination by AODV routing. If the routing is failing, the station will reroute it. Secondly, the stations start RTS/CTS/data/ACK packets switching after the completed AODV routing. If no error of the packets switching occurs, the source will increase by one and resets f to zero. Otherwise, it resets s to zero and increases f by one. Finally, the source checks the values of s and f. If s = S, it will increase the transmission rate to the next higher one. Conversely, if f = F, it will decrease the transmission rate to the next lower one.

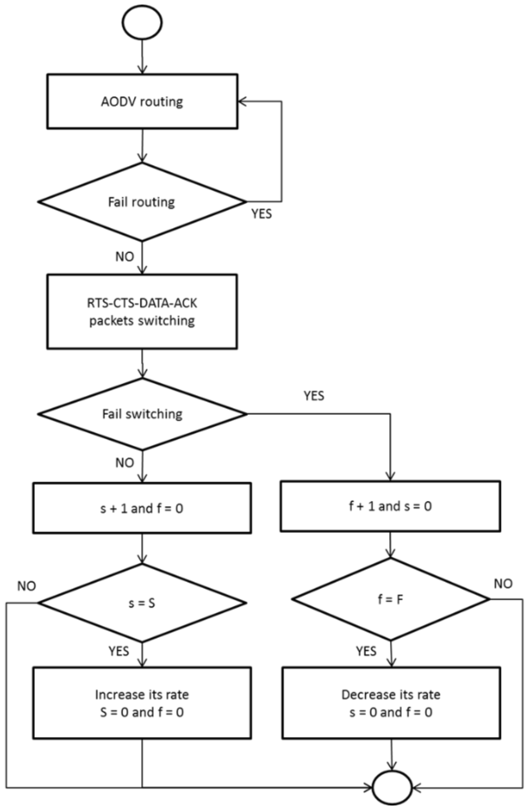

Fig. 2. The flow chart of ARF algorithm

IV. SIMULATION RESULTS

It is considered that an ad hoc network of the IEEE 802.11b WLAN [1] under the DCF mode. The WLAN is under a saturated traffic. The RTS-CTS scheme is turned off. The ACK control frame is transmitted at 1 Mbps and the different PHY rates of the IEEE 802.11b are used. Each station transmits with 20 dBm power. The Log-distance path loss model is used and the path-loss exponent is set to four to consider the indoor office environments [11]. The background noise is set to -96 dBm and the impulse noise to Gaussian noise ratio R is set to 100 [17]. Other parameters are listed in Table 2 and the same as [8].

Each stations move randomly and freely without directional restrictions, i.e., the destination, speed and direction are all chosen randomly and independently of other nodes. Stations velocities are assumed by an uniform distribution (~Uniform (0,1)) in meters per second.

TABLE II. PARAMETERS

Parameter	Value	Parameter	Value
Slot Time	20 µs	MAC Header	272 bits
SIFS	10 µs	PHY Header	192 bits
DIFS	50 µs	RREQ	176 bits
CW_{min}	31	RREP	176 bits
CW_{max}	1023	ACK	112 bits
Payload	12000 bits		

Firstly, we compare fixed rate with adaptive rate with S and F under different channel scenarios. Fig.3 and Fig.5 illustrate the throughput results in pure AWGN and pure Rayleigh channel respectively. Because the probability of collision is very low when the number of stations is small, the highest throughput is at 11Mbps. But errors are increasing when the number of stations gradually increasing and leading to the network's throughput decreasing. However, comparing fixed rate with adaptive rate, the former seriously decline. Fig.4 andFig.6 illustrate the throughput of fixed rates rapidly declining in the channel of the presence of impulse noise. However, ARF algorithm has adjustable characteristic, so when the number of stations increases, packet errors would not be so seriously increase.

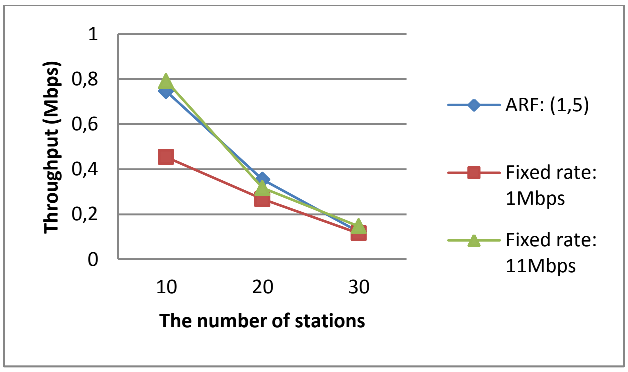

Fig. 3. Throughput results in AWGN channel without impulse noise

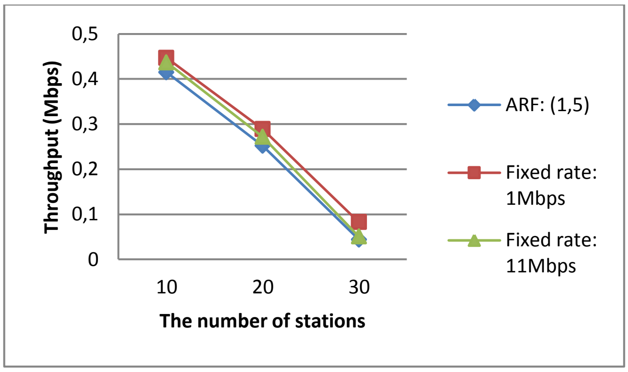

Fig. 4. Throughput results in AWGN channel with impulse noise when R = 100

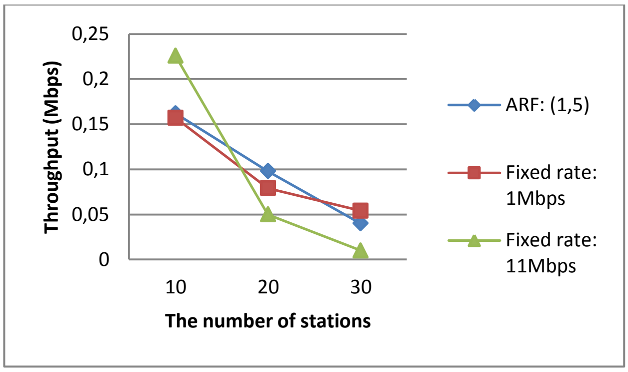

Fig. 5. Throughput results in Rayleigh channel without impulse noise

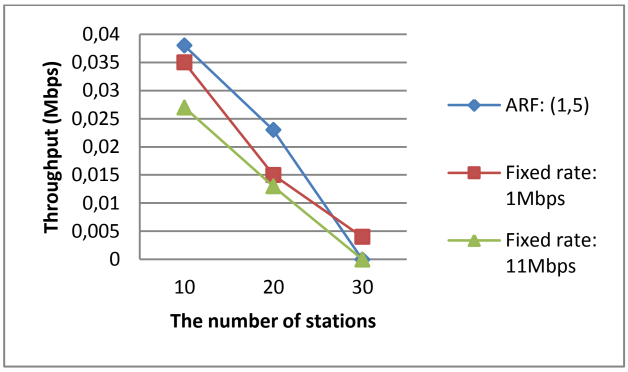

Fig. 6. Throughput results in Rayleigh channel with impulse noise when R = 100

Next, we discuss two combinations (S,F), (1,5) and (5,1). In Fig.7, the case of S = 5 would be more difficult than S = 1 to enhance the throughput when the channel is getting better. By contrast, because the level of change of PHY rate is lower than channel environments, the case of F = 5 would be more difficult than F = 1 to improve the throughput when the channel is getting worse.

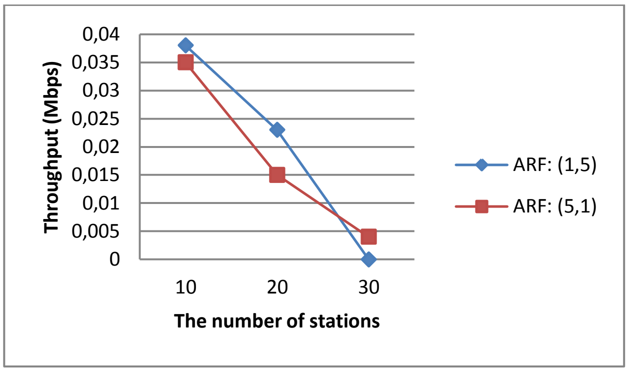

Fig. 7. Throughput results of two combinations of (S, F) in Rayleigh channel with impulse noise when R = 100

Finally, we discuss three velocity ranges of stations with ARF (1,5) and at 1 Mbps, stationary, 0 to 1 and 0 to 2 in meters per second respectively in Rayleigh channel with impulse noise when R = 100. Fig.8 and Fig.9 illustrate that the case of 0 to 2 is the worst throughput. Because it is very possible that the velocity range of 0 to 2 is faster than others, the established route can be invalid. In addition, it takes a lot of time to re-establish the route between the source and the destination.

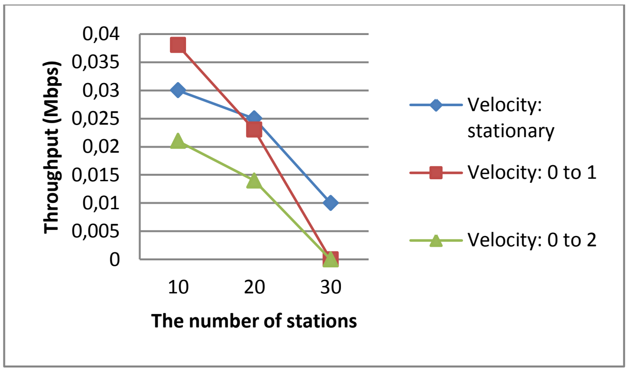

Fig. 8. Throughput results of three velocity ranges of stations with ARF (1,5) in Rayleigh channel with impulse noise when R = 100.

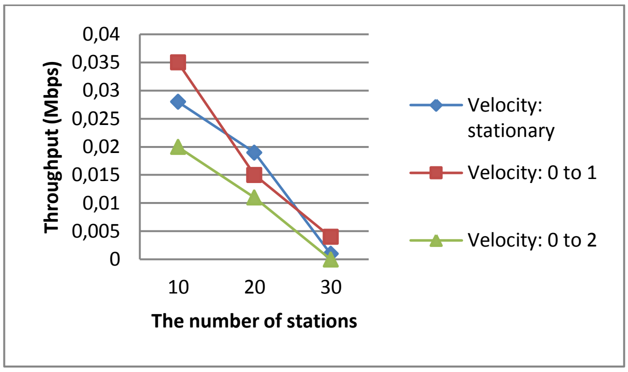

Fig. 9. Throughput results of three velocity ranges of stations at 1 Mbps in Rayleigh channel with impulse noise when R = 100.

V. CONCLUSION

In previous papers, they do not consider IEEE 802.11 ad hoc WLANs with mobile stations which have random mobile speed and no directional restrictions under the time varying Rayleigh channel. In this paper, we consider above mentioned situations and impose an impulse noise model on channel effects. And we use the ARF algorithm to promote the throughput.

In this paper, we analyze throughput of mobile ad hoc networks with IEEE 802.11b over fading channels with impulse noise, and consider two cases: 1) the system with ARF algorithm and 2) the system with fixed rate. The simulated results show that the system with ARF algorithm has the throughput like the best 11 Mbps mode when the channel is AWGN without impulse noise. However, the system with ARF algorithm has the throughput like the beset 1 Mbps mode when the channel is Rayleigh without or with impulse noise. In addition, we consider that velocity ranges of stations impact on throughputs. The results show that the throughput is worse than others when the velocity range is greater.

Finally, we discuss that two cases impact on throughputs, combinations (S,F) and velocity ranges of stations respectively. In the case of combinations (S,F), S = 5 would be more difficult than S = 1 to enhance the throughput when the channel is getting better. By contrast, F = 5 would be more difficult than F = 1 to improve the throughput when the channel is getting worse. In the case of velocity ranges, the throughput is worse than others when the velocity range is greater.

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