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Study and Analysis of Impact of Mobility on the Performance of Ad-Hoc Wireless Networks

Dr B.Lalitha[1], Dhanaveera Pavan Kumar B[2], Dr. T Venkata Naga Jayudu[3], Dr. R Lokanadham[4], Tummapudi sunil[5]

[1]Associate professor in CSE, JNTUA College of Engineering Kalikiri, Andhra Pradesh, India.
[2]Assistant Professor, DEpartment of Computer Science and Engineering, Malla Reddy Engineering College (Autonomous), Main campus,Maisammaguda, Dhulapally (Post via Kompally) Medchal, Malkajgiri-500100.
[3]Associate Professor, Department of Computer Science and Engineering, Srinivasa Ramanujan Institute of Technology, Ananthapuramu, Andhra Pradesh, India.
[4]Professor, Department of Mechanical Engineering, Narsimha Reddy Engineering College, Telangana, India
[5]Assistant Professor, CSE(Data science) Dept, Mallareddy Engineering college(Autonomous) Main campus,Maisammaguda, Dhulapally (Post via Kompally) Medchal, Malkajgiri-500100.

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Abstract

A semi-analytical approach is proposed to incorporate the effect of mobility on the performance of ad-hoc wireless networks. To quantify the impact of mobility using this approach, an ideal network communication scenario without inter-node interference and a realistic network communication with inter-node interference have been considered. Apart from it, the Reserve-and-Go (RESGO) MAC protocol has been characterized by multi-hop route reservation and an absence of collision-based retransmission in intermediate links. This approach has also been investigated the relation between mobility models (i.e. DP (Direction Persistent) and DNP (Direction Non Persistent)), their switching strategies (i.e. RBS (Reservation Based Switching) and ONRBS (Oppurtuitistic Non Reservation Based Switching)) and their impact on BER (Bit Error Rate) performance at multi hop route.

Keywords-RESGO, DP, DNP, RBS, ONRBS, BER etc.

1. INTRODUCTION

To incorporate the effects of node mobility on the performance of ad hoc wireless networks, a semi-analytical approach for quantifying the impact of mobility is proposed. An ideal network communication scenario, without inter-node interference (INI), and a realistic network communication scenario, with INI have been considered. The Reserve-and-Go (RESGO) MAC protocol has been characterized. Two possible switching strategies are considered: (i) Opportunistic non-reservation based switching (ONRBS), where successive hops from source to destination are dynamically chosen based on their length (ii) Reservation based Switching (RBS), where successive hops of multi hop route are activated consecutively regardless of their actual length. Two different mobility models denoted as Direction Persistent (DP) and Direction Non Persistent (DNP) are considered. Numerical results, in the terms of the bit error rate (BER) at the end of a multi-hop route with an average number of hops, are presented to access the performance of the considered ad hoc wireless network communication schemes.

The impact of the switching techniques, the mobility model, the message length and the maximum node speed has been evaluated.

NETWORK COMMUNICATION SCENARIO

A node transmits information only after reserving a multi-hop route to its desired destination. In order to derive an analytical model to capture the impact of node mobility, it is assumed that N nodes are placed at the vertices of a square grid over a circular surface with area A; any multi hop route is constituted by a sequence of hops between neighboring nodes.
The distance between two neighboring nodes,

$$d_{link} = \frac{1}{\sqrt{\rho s}} \quad (1)$$

where node spatial density, ρ_s= N/A
BER (Bit Error Rate) at the end of a multi hop route with $n_h$hops ,

$$BER_{route}^{(n_h)} = 1 - (1 - BER_{link})^{n_h} \quad (2)$$

According to Friss free space formula, the received signal power at a distance d_{link} from the transmitter (i.e. received signal power in a single link transmission),

$$P_r = \frac{\alpha P_t}{d_{link}^2} = \frac{G_t G_r c^2 P_t}{(4\pi)^2 f_1 f_c^2 d_{link}^2} \quad (3)$$

Where P_t is the transmit power (it is assumed to be common for all nodes); $G_t$and G_r are the transmitter and receiver antenna gains; f_c is the carrier frequency; c is the speed of light; and $f_1 \geq 1$ is a loss factor. In this case, it is considered that $G_t = G_r = 1$ (omnidirectional antennas) and $f_1 = 1$(no system losses).

A. Ideal (no Inter Node Interference (NI))Case

The link SNR (Signal to Noise Ratio),

$$SNR_{link} = \frac{E_{bit}}{E_{thermal}} \quad (4)$$

where$E_{bit} \triangleq P_r/R_b$is the received energy per bit and $E_{thermal}$is the thermal noise power spectral density which can be written as FkT_0, where F is the noise figure, k= 1.38 × 10^{-23} J/K is Boltzmann's constant and T_0 is the noise temperature (T_0 = 300K). Therefore link SNR,

$$SNR_{link} = \frac{\alpha P_t}{FkT_0 R_b d_{link}^2} \quad (5)$$

link BER,

$$BER_{link} = Q\left(\sqrt{2\, SNR_{link}}\right) = \frac{1}{\sqrt{2\pi}} \int_{\sqrt{2\, SNR_{link}}}^{\infty} e^{-x^2/2}\, dx \quad (6)$$

B. Realistic (Inter Node Interference (INI))Case

The link SNR with interference noise,

$$SNR_{link}^{int} = \frac{E_{bit}}{E_{thermal} + E_{int}} \quad (7)$$

Where interference energy $E_{int} = P_{int}/B$

Where P_{int} is the received interference power and B is the transmission bandwidth.
The route BER with RESGO MAC protocol,

$$BER_{route}^{RESGO} \backsimeq \bar{n}_h \frac{c_{aLOS} \lambda M}{R_b} \quad (8)$$

Where M is the message length and c_{aLOS}= 0.75. The route BER with RESGO MAC protocol depends only on the traffic load λM and the data rate R_b but not on the density.

MOBILITY MODELS

The mobility of a node is described in terms of its speed, denoted as υ and its direction angle (with respect to a horizontal axis), denoted as θ. A statistical approach for two possible mobility models is discussed.

C. Direction-Persistent (DP)Mobility Model

The transmission of a message, the direction and the speed of the two nodes at the ends of a link are constant. Based on this assumption, this mobility model is combined with two switching stratigies.

A.1.Opportunistic Non- reservation-Based Switching(ONRBS)

Consecutive links are considered ‘independent’ of each other. The mobility of a node during message transmission over a link (i.e. final node) will be independent of its mobility during the message transmission in the consecutive link (i.e. beginning node). During a message transmission of an intermediate link of a multi-hop route, two nodes of a link as n_A and n_B are considered.These nodes have constant speeds and direction angles, denoted as (υ_A, θ_A) and (υ_B, θ_B), during the transmission of a message.the link statuses at the activation ($t = t_s$) and at the end ($t = t_e = t_s + D_{msg}$) of a message transmission are shown in **Fig(1)**.

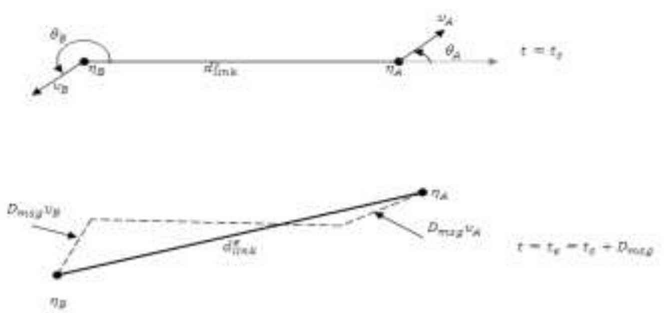

Fig (1): Link evolution during message transmission in DP mobility model

Final link length,

$$d_{link}^{e} = [d_{link}^{2} + D_{msg}^{2}(\upsilon_A^2 + \upsilon_B^2) - 2\upsilon_A\upsilon_B D_{msg}^{2}\cos(\theta_A - \theta_B) + 2d_{link}D_{msg}(\upsilon_A\cos\theta_A - \upsilon_B\cos\theta_B)]^{0.5} \quad (9)$$

Where d_{link} is the initial distance and starting link length, $d_{link}^{s} = d_{link} + d_{link}^{e}$.

Arithmetic mean between d_{link}^{s} and d_{link}^{e},

$$\bar{d}_{link} \triangleq \frac{d_{link}^{s} + d_{link}^{e}}{2} = \frac{d_{link}}{2} + \frac{1}{2}[d_{link}^{2} + D_{msg}^{2}(\upsilon_A^2 + \upsilon_B^2) - 2\upsilon_A\upsilon_B D_{msg}^{2}\cos(\theta_A - \theta_B) + 2d_{link}D_{msg}(\upsilon_A\cos\theta_A - \upsilon_B\cos\theta_B)]^{0.5} (10)$$

By referring eq.(8), the route BER,

$$BER_{route} = max\{BER_{route}^{Gauss}, \bar{n}_h \frac{c_{aLOS}\lambda M}{R_b}\} \quad (11)$$

Where, $BER_{route}^{Gauss} = \frac{\sum_{j=1}^{\eta} BER_{route}(\zeta_{ONRBS}^{(j)})}{\eta}$ (12)

Where ζ indicates realization to the link j BER in Gauss route.

A.2.Reservation-Based Switching(RBS)

Once a multi-hop route has been established, a message flows through the originally reserved links of the route. When a message reaches an intermediate link of the route, the message transmission over this link is activated regardless of the corresponding link length. This is shown in **Fig.(2)**

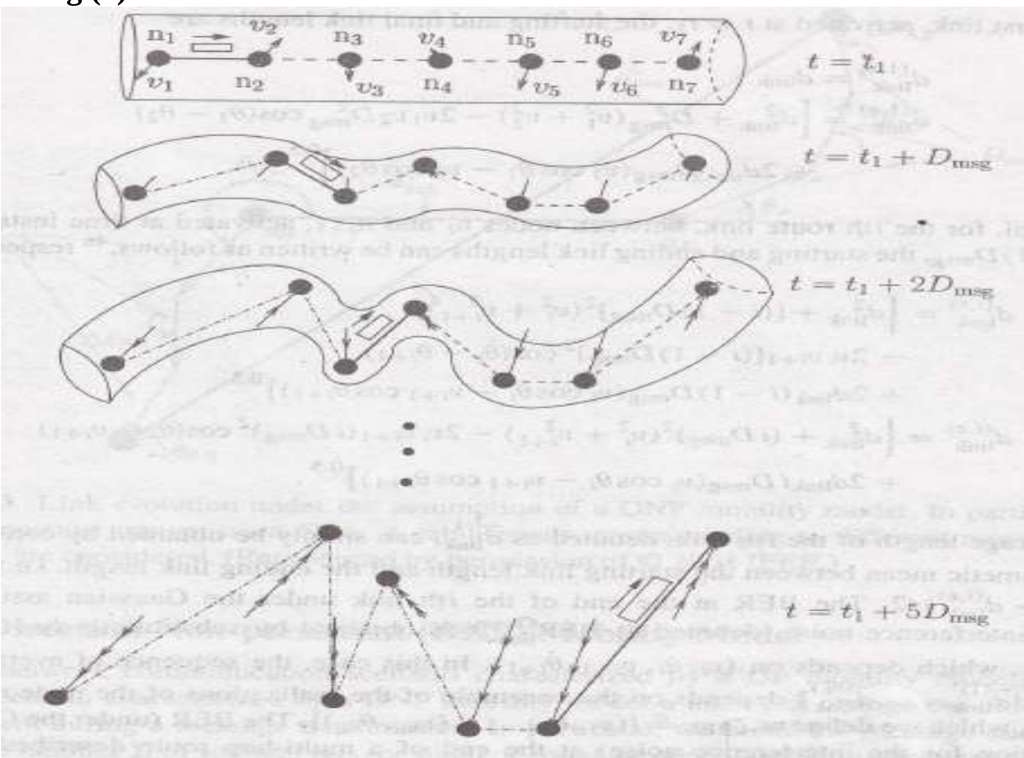

Fig (2) : Route evolution during a message transmission in RBS

where it is assumed that mobility of each node remains constant for the entire transmission along the activated route. Each communication route is visualized as a 'tube', inside which the messages generated at the source node flow to the destination node, at the end of the tube. For a particular sequence of a node mobility, while a message flows along the route, the corresponding tube bends due to node mobility.

For the first link, activated at t = t_1, the starting and final link lengths,

$$d_{link}^{(1,s)} = d_{link}$$

$$d_{link}^{(1,e)} = [d_{link}^2 + D_{msg}^2(v_1^2 + v_2^2) - 2v_1v_2D_{msg}^2\cos(\theta_1 - \theta_2) + 2d_{link}D_{msg}(v_1\cos\theta_1 - v_2\cos\theta_2)]^{0.5} \quad (13)$$

In general, for the i^{th} route link, between nodes n_i and n_{i+1}, activated at time instant t=t_1=(i-1)D_{msg}, the starting and ending link lengths,

$$d_{link}^{(i,s)} = \{d_{link}^2 + [(i-1)D_{msg}]^2(v_i^2 + v_{i=1}^2) - 2v_iv_{i+1}[(i-1)D_{msg}]^2\cos(\theta_i - \theta_{i+1}) + 2d_{link}(i-1)D_{msg}(v_i\cos\theta_i - v_{i+1}\cos\theta_{i+1})\}^{0.5} \quad (14)$$

$$d_{link}^{(i,e)} = \{d_{link}^2 + (iD_{msg})^2(v_i^2 + v_{i+1}^2) - 2v_iv_{i+1}(iD_{msg})^2\cos(\theta_i - \theta_{i+1}) + 2d_{link}iD_{msg}(v_i\cos\theta_i - v_{i+1}\cos\theta_{i+1})\}^{0.5} \quad (15)$$

The average length of the i^{th} link,

$$\bar{d}_{link}^{(i)} = (d_{link}^{(i,s)} + d_{link}^{(i,e)})/2 \quad (16)$$

The BER at the end of a multi-hop route with an average number of hops,

$$BER_{route}^{Gauss} = \frac{\sum_{j=1}^{\eta} BER_{route}^{Gauss}(\zeta_{RBS}^{(j)})}{\eta} \quad (17)$$

D. Direction-Non-Persistent (DNP)Mobility Model

A node can change the direction of a movement during a message transmission. The message duration is broken into a finite number ∑ of subintervals or slots of equal duration. Neglecting the propagation time, in each slot a node, moving at speed υ, covers a distance equal to $D_{msg}\upsilon/\sum$.

B.1.Opportunistic Non- reservation-Based Switching(ONRBS)

The average link length in thejth slot,

$$\bar{d}_{link\ j} = \frac{d^{s}_{link\ j} + d^{e}_{link\ j}}{2}, \text{ j = 1, ….., } \sum \qquad (18)$$

The average link length during a message transmission,

$$\bar{d}_{link} = \frac{\sum_{j=1}^{\Sigma} \bar{d}_{link\ j}}{\Sigma} \qquad (19)$$

It is possible to compute the average BER and the final expression for the route BER is obtained through the equation (17).

B.2. Reservation-Based Switching(RBS)

The BER at the end of a multi-hop route (under the Gaussian assumption for the interference noise) corresponding to the 'overall' realization$\acute{\zeta}_{RBS}$,

$$\mathrm{BER}^{\mathrm{Gauss}}_{\mathrm{route}}(\acute{\zeta}_{\mathrm{RBS}}) = 1 - \prod_{i=1}^{\bar{\eta}_h - 1} [1 - \mathrm{BER}^{\mathrm{Gauss}}_{\mathrm{link\,i}}(\upsilon_i, \theta_i, \Delta\theta_i^{\mathrm{RBS}}, \upsilon_{i+1}, \theta_{i+1}, \Delta\theta_{i+1}^{\mathrm{RBS}} \qquad (20)$$

Where sequence of mobility realization for all node,

$$\acute{\zeta}_{\mathrm{RBS}} \triangleq (\upsilon_1, \theta_1, \Delta\theta_1^{\mathrm{RBS}}, \ldots\ldots, \upsilon_{\bar{\eta}_h}, \theta_{\bar{\eta}_h}, \Delta\theta_{\bar{\eta}_h}^{\mathrm{RBS}}) \ (21)$$

The vector realization containing the angular direction changing for the ith node,

$$\Delta\theta_i^{\mathrm{RBS}} \triangleq \left(\Delta\theta_{i,1}; \ldots; \Delta\theta_{i,\Sigma-1}; \ldots; \Delta\theta_{i,(i-1)(\Sigma-1)+1}; \ldots \Delta\theta_{i,1(\Sigma-1)}\right).(22)$$

2. RESULTS AND CONCLUSION

E. Direction-Persistent (DP)Mobility Model

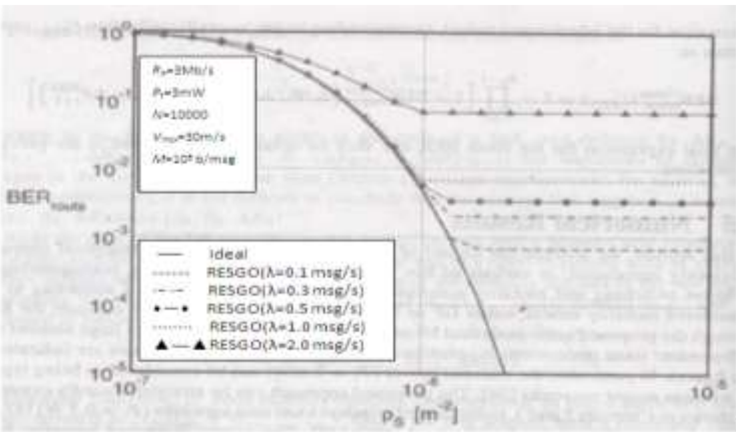

Fig (3): Route BER versus node spatial density in DP mobility model and ONRBS

Fig. (3) Shows the BER performance in the case of ONRBS as a function of node spatial densityρ_s. A network communication scenario with N = 10^4 nodes ($\bar{\eta}_h = 20$) and message length M = 10^5 b/msg and the maximum node speed $\upsilon_{max}$of 30 m/s is considered. For $\lambda \leq 1$

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msg/b, the route BER coincides with that in ideal case in the region. If traffic load is high ($\lambda \geq$ 2 msg/b), then the route is also worse than that in ideal case. ONRBS is robust against node mobility for low interference and the performance depends on the interference level.

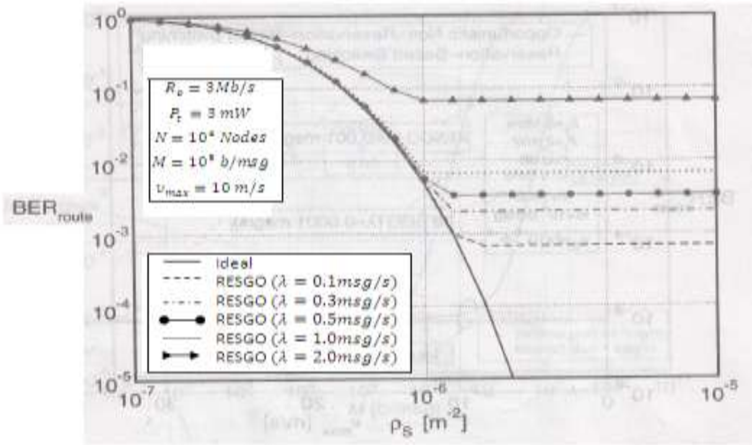
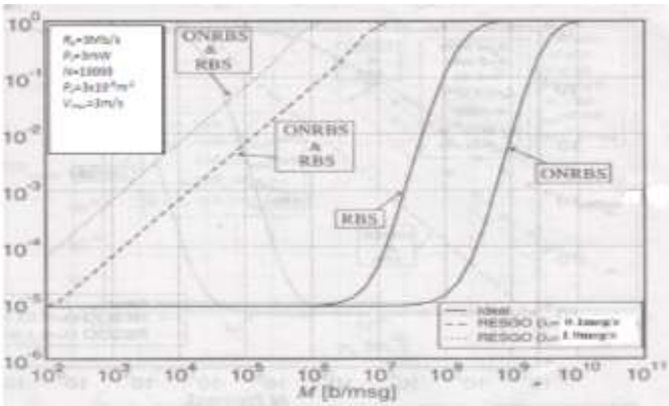


Fig. (4) Route BER versus node spatial density in DP mobility model and RBS

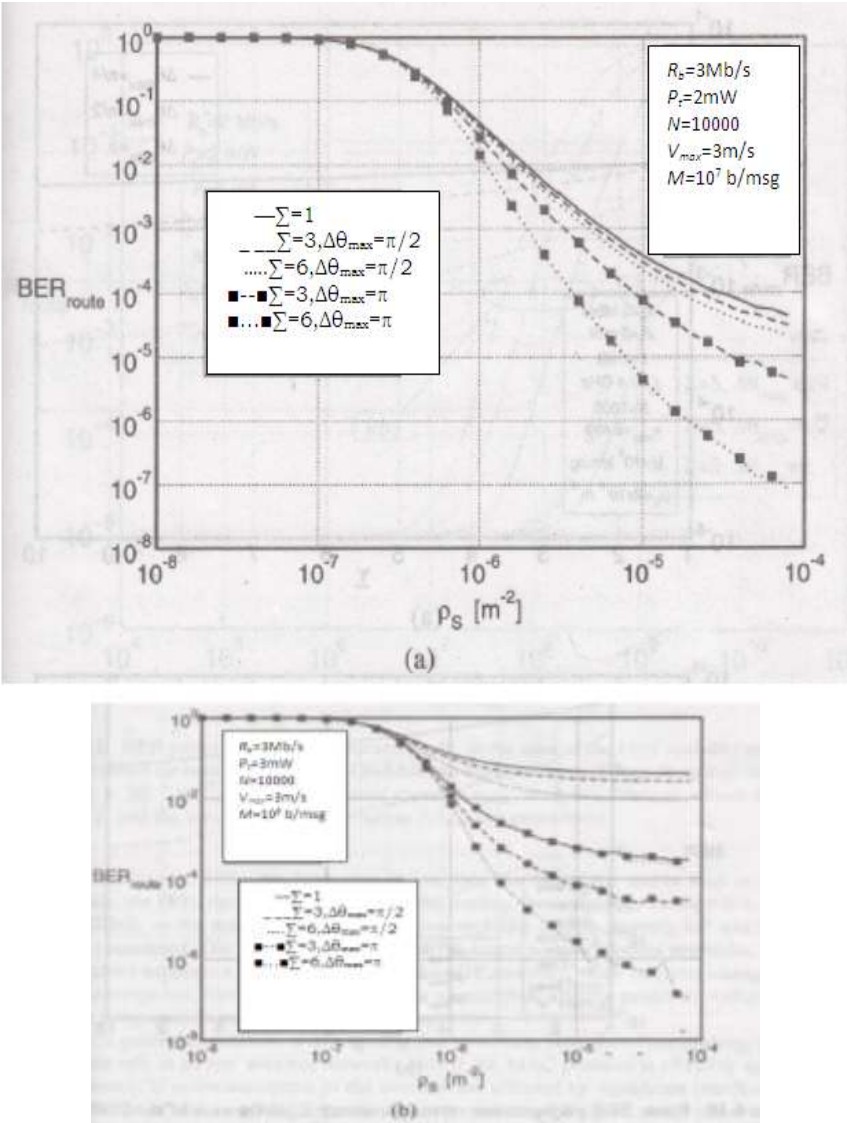
Fig. (4) shows the BER performance in the case of RBS as a function of node spatial density ρ_s. A network communication scenario with N = 10^4 nodes ($\bar{\eta}_h = 20$) and message length M = 10^5 b/msg and the maximum node speed $\upsilon_{max}$of 10 m/s is considered. The performance is similar to that observed in ONRBS. If MAC protocol is not effective in rejecting interference (RESGO), then the performance of ad hoc wireless network with mobility nodes is determined by multiple access interference.



FIG, (5) BER performance versus message dimension M in DP mobility model

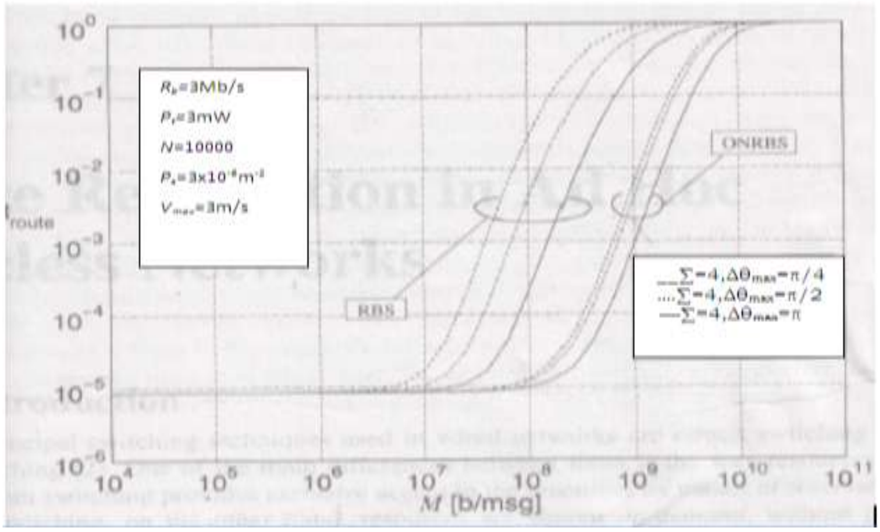
Fig. (5) shows the dependence of the route BER on the message length for a low mobility node and speed
υ_{max}Of3 m/s. for increasing message length (transmission duration), the route BER reaches 1 i.e. the performance becomes unacceptable. In the ideal case, there is significant difference between the performance with ONRBS and RBS (at a maximum route BER equals to 10^{-4}, the maximum length with ONRBS is M $\simeq 6 \times 10^6$ b/msg, whereas with RBS is M $\simeq 2.5\times 10^5$ b/msg), in a realistic case (with interference and average packet generation rate equal to 0.1 and 1.0 msg/s respectively).

F. Direction-Non-Persistent (DNP)Mobility Model



Fig, (6) Route BER performance versus node spatial density ρ_s, for DNP mobility model with (a) ONRBS and (b) RBS

Fig. (6) shows the route BER performance as a function of the node spatial density for ONRBS and RBS. All the major network parameters, expect for the message length, are the same in both cases. The message length M is 10^7 b/msg for ONRBS and 10^6 b/msg for RBS respectively. In both cases, three possible values for the parameter ∑ (1,3 and 6) and two possible values for maximum angular deviation $\Delta\theta_{max}$ ($\pi/2$ and π) are considered. By increasing of ∑ and/or $\Delta\theta_{max}$, route BER performance of BER is more prominent than ONRBS. With ∑ = 1,3,6, the performance of ONRBS is more independent of $\Delta\theta_{max}$than that of RBS.



Fig, (7) BER performance versus parameter M, in DNP mobility model for ONRBS and RBS

Fig.(7) shows BER performance as a function of message length M in both ONRBS and RBS. The parameter ∑ is fixed to 4, and various values of maximum angular deviation $\Delta\theta_{max}$ are considered. An increase in $\Delta\theta_{max}$alleviates the degradation by node mobility.

Thus the relation between node mobility, switching strategy and physical layer characteristics, and their impact on the BER performance at the end of multi hop route have been investigated using a semi-analytical approach. The results show that ONRBS supports heavier control traffic, a higher mobility than that of RBS. It is also shown that larger the traffic load is, the lower the routing or switching strategy on the network performance.RBS based ad hoc wireless networks in DNP mobility model gives a better performance than DP mobility, since frequent changes of directions average out, forcing the nodes to move around their original positions, rather than moving far away and, therefore disrupting connectivity.

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