

Pheromone Termite (PT) Model to Provide Robust Routing over Wireless Sensor Networks

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Abstract—In this paper, a scalable mobility-aware pheromone termite (PT) analytical model is proposed to provide robust and faster routing for improved throughput and minimum latency in Wireless Sensor Networks (WSNs). PT also provides support for the network scalability and mobility of the nodes. The monitoring process of PT analytical model is based on two different parameters: packet generation rate and pheromone sensitivity for single and multiple links.

The PT routing model is integrated with Boarder node medium access control (BN-MAC) protocol. Furthermore, we deploy two other known routing protocols with BN-MAC; Sensor Protocols for Information via Negotiation (SPIN) and Energy Aware routing Protocol (EAP). To demonstrate the strength of the PT model, we have used ns-2.35-RC7 to compare its Quality of Service (QoS) features with competing routing protocols. The simulation results demonstrate that the PT model is scalable and mobility-aware protocol that saves energy resources and achieves high throughput.

Index Terms— Pheromone Termite (PT) Model, Boarder Node Medium Access Control (MAC) Protocol, Mobility, Routing, packet generation rate and pheromone sensitivity.

I. INTRODUCTION

Wireless Sensor Networks consist of small size sensor nodes. Each sensor node works as a unit with sensing capabilities to collect and process data to achieve a collective goal. The sensors are deployed to observe the activities of events in the intended areas of interest [1]. Therefore, it is important to design a system that should be energy efficient at all the levels of the protocol stack. An efficient MAC protocol substantially improves the WSN performance as sensor nodes consume significant energy for accessing the channel. The channel access process is performed by the MAC protocols [2]. Any MAC protocol can be classified as contention-based or scheduled-based [3].

Contention based MAC protocols are simple and easier to use without synchronization. However, each sensor in contention-based MAC protocol keeps its radio on for a long period of time that causes the energy depletion [4]. Alternatively, scheduled based protocols use time division

multiple access (TDMA) mechanism to decrease the energy consumption. From the other side, scheduled based MAC protocols experience do not support scalability and mobility of the nodes [5]. As a result, broken links occur.

Few cross layer MAC protocols are found in literature, which reduce the energy consumption by adjusting the reliable link and bandwidth constraints [6]. However, these protocols experience co-channel interference due to long state transitions [7]. End-to-end delay can be minimized by combining the MAC and network layer features [8]. Also, end-to-end delay can be guaranteed while choosing the best least delayed path [9].

The reported MAC protocols in literature are not fully capable to support mobility and network adaptability. There are several issues which need to be addressed when designing a highly robust MAC protocol. To address these concerns, PT model is integrated with BN-MAC to support mobile nodes [10]. With the integration of PT with BN-MAC, several WSN applications can be supported using less energy such as disaster recovery, surveillance, monitoring, home automation devices and controlling remote devices. Furthermore, PT routing model provides cross-layering support for BN-MAC to handle mobility and scalability over WSNs.

II. SYSTEM MODEL FOR BN-MAC PROTOCOL

BN-MAC is an energy efficient protocol that reduces the energy consumption while handling idle listening, overhearing and congestion. It also shortens the latency while guarantying high reliability in a mobile environment [12].

Let us assume that the system model should be composed of many small nodes, which are organized in ad-hoc fashion. The nodes should use short range and one-hop communication rather than long range communication to save the energy. In our case, we use 1-hop destination search for scheduling and sending the data. The WSN system model is divided into different regions and each region is controlled by a boarder node (BN) as shown in Figure 1. The BN plays a role as the coordinator to forward the data within the region and the adjacent region.

The message forwarding process of BN-MAC protocol involves two types of communications; intra and inter. Intra communication process is carried within the region while inter communication process is performed out of the region. The mode of communication within the region is based on Anycast communication. Anycast communication reduces the latency as compared with multicast communication. The multicast consumes more energy while forwarding the packets. Furthermore, larger packet size severely affects the network performance during the multicasting.

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We prefer to use Anycast communication to reduce the overhead of packet forwarding from each node. The most of latest WSNs applications are in the surveillance and monitoring area. For such applications, mobility and high packet generation rate of the network are mandatory requirements. If most of the nodes remain in an idle state for a longer time, considerable amount of energy is wasted. In our case a sensor node does not remain in an idle state because once the node finishes its monitoring process, it switches to a sleep state using the Automatic Active and Sleep model presented in [2]. We use BN-MAC with PT for controlling the stationary and mobile devices from remote places as depicted in Figure 1.

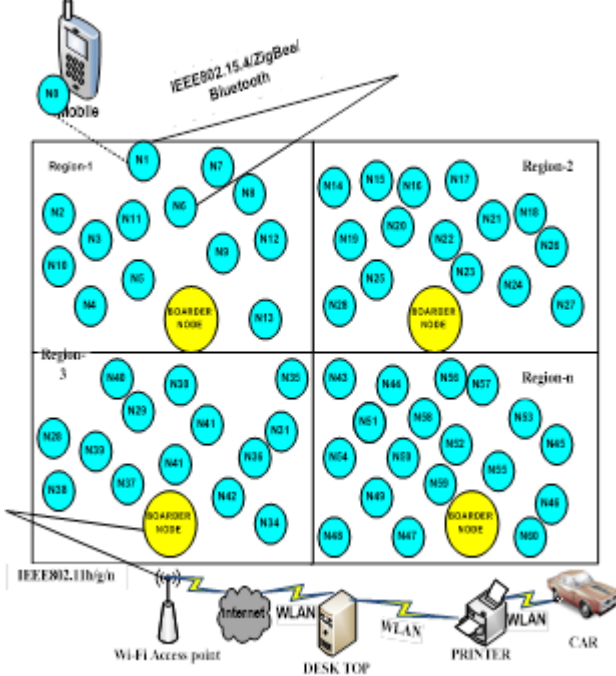


Figure 1. Proposed simulated scenario for handling the devices from remote distance over wireless sensor network (WSN)

III. PHEROMONE TERMITE MOBILITY-AWARE MODEL FOR BN-MAC

BN-MAC protocol leverages both the features of Carrier Sense Multiple Access (CSMA) and Time Division Multiple Access (TDMA). CSMA is based on semi synchronous mechanism supported with low duty cycles. From the other side, scheduled based part uses PT protocol that provides the cross layering support for finding the best route to forward and receive the data packets at one-hop neighbor nodes.

Once the carrier medium is accessed, the sensor nodes are scheduled for sending the data using pheromone mobility aware route. Let us assume that 'P_l' is the variable length of packets forwarded to other neighbor nodes. The distance between the two nodes is 'r'. Thus, according to Newton's law of gravitation, the distance is inversely proportional to the force [13]. Therefore, we can apply free space propagation model to measure the distance between two neighbor nodes based on the following parameters.

D_{te} : Default transmitted energy

E_t : Energy gain of transmitter (TX)

E_r : Energy gain of receiver (RX)

L_t : location of transmitter (Tx)

L_r : location of receiver (RX)

pl : Received packet length

LN : Loss in network.

Then r can be calculated as shown in equation (1)

$$r = \frac{2\sqrt{Dte * Et * Er * Lt^2 * Lr^2}}{pl * LN} \quad (1)$$

The calculated distance is used for updating the trajectory pheromone of sensor nodes. We hereby deploy the features of trail pheromone and ant control algorithm.

$$P_{l,s}^{(N)} = \left\{ P_{l,s}^{(N)} * e^{-(rc-rsn)\beta} \right\} + P_a ; l = H_p(2)$$

Where $P_{l,s}^{(N)}$ is the number of pheromones that source sensor node 's' spreads on the link at the one-hop neighbor 'l' for node 'n'. 'H_p' is the previous destined hop of packet, 'P_a' is the amount of pheromone used in each destined packet. 'r_c' is the current distance of neighbor node 'n' at link 'l' and 'e' is the distance of same neighbor node 'l' when the last packet is received and 'β' is the packet-generation rate. The calculated trail pheromone is used to determine the forwarding energy power of each neighbor node. Packet forwarding power of each neighbor node can be calculated as follows:

$$P_{q,r}^{(N)} = \frac{(P_{q,r}^{(N)} +)^{P_s}}{\sum_{u=1}^K (P_{u,r}^{(N)} +)^{P_s}} \quad (3)$$

Where, $P_{q,r}^{(N)}$ is the energy power of each neighbor node 'u' to forward the packet destination 'r' at node 'n' and 'K' is total number of neighbor nodes. 'C' is pheromone threshold that is constant. P_s is the level of pheromone sensitivity. Pheromone threshold and pheromone sensitivity can also be used to find the second best alternate path of forwarding the packets to destination.

We determine an average predictable amount of pheromone 'Pψ' using different links. Let us assume 'A' is the source node and 'B' is the destination node, which are using two different links from the list $l_1, l_2, l_3, l_4, \dots, l_n$ for sending pheromone. Each link consists of different attributes that are characterized by non-negative random operation 'λ_o(r)' with mean value Φ_o(r).

Each packet forwards a fixed amount of pheromone 'P_a'. Let us assume that each node generates pheromone at constant rate 'β'. Suppose two nodes: 'A' and 'B' are located at two different locations with distance 'r' which are uniformly distributed over the network. Thus, Rayleigh Distribution can be used to find the distance distribution of nodes. If transmission power of sensor node is less than WSN area, then the distribution distance is divided into range of 0 to r that can be calculated as:

$$U(r) = \frac{R_e^{-R\beta} / (2R^2)}{R^2} \quad (4)$$

This is the probability density function that is used to determine the density of the WSN [14].

$$V(r) = \frac{R_e^{-R\beta} / (2R^2)}{R^2} \quad (5)$$

Where, 'V(r)' is the node distribution that can be used to compute the predicted pheromone generation $P(R_e^{-R\beta})$ between the node distribution distance 'r' with respect to the number of arrived packets.

Let us assume 'Z' is a random variable that is used to describe the fraction of generation pheromone $Z = (R_e^{-R\beta})$ between node distribution distance 'r' corresponding to packet arrival rate. Thus, predicted amount of pheromone can be computed using 'V(r)'.

For $0 \leq r \leq R$ as follows:

$$V(r) = \frac{R_e^{-R\beta}}{R^2} \quad \text{for } 0 \leq r \leq R \text{ and } Z = (R_e^{-R\beta}), \text{ then}$$

$$r = \frac{-\log z}{\beta} \quad \left(\frac{rr}{rz}\right) = \frac{-1}{z\beta}$$

$$V(Z) = V(r) \left| \frac{rr}{rz} \right|$$

$$V(Z) = \frac{2}{R^2} \frac{(\log z)}{\beta} * \left| \frac{-1}{z\beta} \right| \quad (6)$$

Enumeration the order of equalities:

$$V(Z) = \frac{2}{R^2 \beta^2} * \frac{1}{Z} (-\log z) \quad R_e^{-r^2} \leq Z \leq 1$$

Thus, degenerated predictable pheromone can be calculated as follows:

$$P(R_e^{-r^2}) = \frac{2}{R^2 \beta^2} [1 - R_e^{-R\beta} (R\beta + 1)] \quad (7)$$

The predicted generation rate can be used to compute the average predictable pheromone amount on the single and multiple links using pheromone update-degeneration function. Let us assume 'P' is the population at the distance 'h' and 'P_i' is the initial population. Thus, 'P' can be derived as follows:

$$\frac{rp}{rh} = \beta p \quad \frac{rp}{p} = \beta * rh$$

$$\log p = -\beta * h + \omega$$

$$p = \omega * R_e^{-\beta * h} \quad (8)$$

The updated pheromone function can also be written as:

$$p = \omega * R_e^{-\beta * h} = \omega * R_e^{-h} * \beta$$

This function is used for calculating an average predicted pheromone amount on the single and multiple links. It is assumed that an average predicted pheromone on the single link can be determined using pheromone update equation for the number of 'n' packets.

Assuming that the number of delivered packets for distance 'r' is Poisson distribution with an average wavelength $\lambda = \frac{v}{f}$ packet/meter.

a. The average amount of received pheromone is 'ω'.

b. Initial pheromone amount 'P_i' on single link.

Thus, the pheromone update equation is used consecutive times 'n'.

$$p(n) = p_i * \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right]^n + \omega$$

$$* \left(\frac{1 - \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right]^n}{1 - \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right]^n} \right)$$

Let $\sigma = \frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)]$ then

$$PP(n) = p_i \sigma^n + \omega * \left(\frac{1 - \sigma^n}{1 - \sigma} \right) \quad (9)$$

Thus, the predicted pheromone amount on the single link for node distribution distance 'r' for number of 'n' arrived packets PP(r) is expressed with Poisson distribution amount $\lambda = \frac{v}{f}$ and given as (10):

$$f(z) = \frac{\lambda^z * R_e^{-\lambda}}{Z!} \quad (10)$$

Where, λ: Average number of successful received packets, and Z: Number of successful attempts.

We map and apply the Poisson distribution 'ψ' in our problem and the details are given as follows:

$$\Delta p = \sum_{i=0}^{\infty} [\Psi_i(\lambda r, n) [p(n)]]$$

$$\Delta p = \sum_{i=0}^{\infty} [R_e^{-\lambda r} \frac{(\lambda r)^i}{i!}] * [p_i \sigma^n + \omega * \left(\frac{1 - \sigma^n}{1 - \sigma} \right)]$$

$$\Delta p = \frac{\omega}{1 - \sigma^n} + R_e^{-\lambda r} \frac{(\lambda \beta r)}{\lambda + \beta} \left(p_i - \frac{\omega}{1 - \sigma} \right) \quad (11)$$

An average pheromone performance for longer time can be obtained as follows:

$$\lim_{r \rightarrow \infty} PP(r) = \frac{\omega}{1 - \sigma}$$

$$\Delta p = \frac{\omega(\lambda + \beta)}{\beta}$$

$$\Delta p = \frac{\omega \left(\frac{v}{f} + \beta \right)}{\beta} \quad (12)$$

If we use only single link for destined the packets, then 'Δp' is the predicted pheromone amount on the single link. Let us assume that the forwarded packets on multiple links as depicted in Figure 2, showing the behavior of termite when attempting to find the food. Similarly, the PT works for WSNs for providing the links on the path. Suppose P₀, P₁, P₂, ..., P_n be the multiple links to forward the data over WSN. The amount of predicted packet degeneration is $(R_e^{-R\beta})$.

Thus, when a packet is received by node 'n', it forwards the packet to 1-hop neighbor nodes; and the pheromone is degenerated on all the links based on predicted packet degeneration rate. Thus, the average pheromone for all the multiple links can calculated as follows:

$$P_{0x}^x = P_{0y}^x * \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right] + \left[\frac{(P_{0x}^y +)^{P_s}}{(P_{0x}^y +)^{P_s} + (P_{1x}^y +)^{P_s} + (P_{2x}^y +)^{P_s} + \dots + (P_{nx}^y +)^{P_s}} \right] * \omega \quad (13)$$

$$P_{1y}^x = P_{1x}^x * \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right] + \left[\frac{(P_{0x}^y +)^{P_s}}{(P_{0x}^y +)^{P_s} + (P_{1x}^y +)^{P_s} + (P_{2x}^y +)^{P_s} + \dots + (P_{nx}^y +)^{P_s}} \right] * \omega \quad (14)$$

$$P_{2y}^x = P_{2x}^x * \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right] + \left[\frac{(P_{0x}^y +)^{P_s}}{(P_{0x}^y +)^{P_s} + (P_{1x}^y +)^{P_s} + (P_{2x}^y +)^{P_s} + \dots + (P_{nx}^y +)^{P_s}} \right] * \omega \quad (15)$$

$$P_{ny}^x = P_{nx}^x * \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right] + \left[\frac{(P_{0x}^y +)^{P_s}}{(P_{0x}^y +)^{P_s} + (P_{1x}^y +)^{P_s} + (P_{2x}^y +)^{P_s} + \dots + (P_{nx}^y +)^{P_s}} \right] * \omega \quad (16)$$

$$P_{0x}^y = P_{0y}^y * \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right] + \left[\frac{(P_{0y}^x +)^{P_s}}{(P_{0y}^x +)^{P_s} + (P_{1y}^x +)^{P_s} + (P_{2y}^x +)^{P_s} + \dots + (P_{ny}^x +)^{P_s}} \right] * \omega \quad (17)$$

$$P_{1x}^y = P_{1y}^y * \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right] + \left[\frac{(P_{0y}^x +)^{P_s}}{(P_{0y}^x +)^{P_s} + (P_{1y}^x +)^{P_s} + (P_{2y}^x +)^{P_s} + \dots + (P_{ny}^x +)^{P_s}} \right] * \omega \quad (18)$$

$$P_{2x}^y = P_{2y}^y * \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right] + \left[\frac{(P_{0y}^x +)^{P_s}}{(P_{0y}^x +)^{P_s} + (P_{1y}^x +)^{P_s} + (P_{2y}^x +)^{P_s} + \dots + (P_{ny}^x +)^{P_s}} \right] * \omega \quad (19)$$

$$P_{nx}^y = P_{ny}^y * \left[\frac{2}{R^2 \beta^2} [1 - R_e^{-\beta R} (1 + \beta R)] \right] + \left[\frac{(P_{0y}^x +)^{P_s}}{(P_{0y}^x +)^{P_s} + (P_{1y}^x +)^{P_s} + (P_{2y}^x +)^{P_s} + \dots + (P_{ny}^x +)^{P_s}} \right] * \omega \quad (20)$$

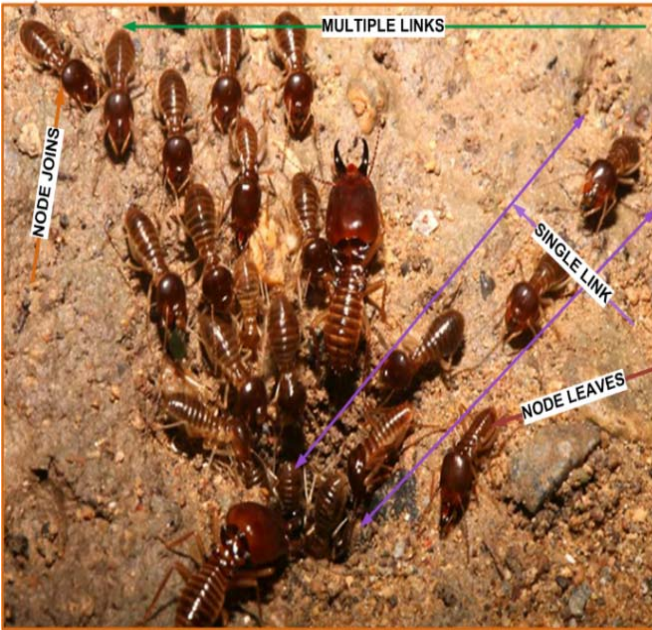


Figure 2. Single and multiple links to forward the packets using pheromone-termite model

IV. SIMULATION SETUP AND ANALYSIS OF RESULTS

We set up a simulation scenario for controlling remote devices over WSN. We use ns-2.35-RC7 that produces results that are almost similar to real environments. In the experiments, the WSN is divided into ‘N’ regions to get the information more quickly.

We have combined mobile-based and static-based scenarios. The main objectives of the simulation is to determine suitable routing protocol for BN-MAC. Thus PT, EAP and SPIN are integrated and simulated with BN-MAC. The simulation scenarios consist of 300 nodes, which are randomly placed in a geographical area of $600 \times 600 \text{ m}^2$. The area is divided into

‘N’ number of $150 \times 150 \text{ m}^2$ regions. The initial energy of each sensor node is set to 20 J.

The bandwidth of the nodes is 40 kb/sec, and the maximum power consumption for each sensor node is set 14 mW. The sensing capability is 13 mW. Each sensor is capable of broadcasting the data at a power intensity ranging from -16 to 13 dBm. The size of the packet is fixed to 128 bytes. The sink location in each region is at the distance of (45, 45). The node mobility is set from 0 m/sec to 18 m/sec. The transmission range of nodes is 30 meters with 10 meter sensing capability.

The total simulation time is 20 minutes, and the pause time is set to 2 sec before start of the simulation. During this phase, nodes are in a warm up phase. The results presented in this paper are an average of 12 simulation runs.

A. Control Packets

The routers consume a substantial amount of energy to send control packets in WSN applications. The control packets are used for the handshaking process which consumes network bandwidth. An energy-efficient routing protocol can minimize the number of control packets that are sent to save energy and bandwidth. Figure 3 presents the control packet overhead of PT, SPIN, and EAP with BN-MAC.

The number of control packets is directly proportional to node mobility. PT outperforms SPIN and EAP. PT is a bio-inspired protocol that does not vary under different mobility conditions, whereas the other mobility protocols experience problems due to changes of mobility. Furthermore, EAP and SPIN suffer due to frequent link break-up because of high mobility and thus require more control packets to re-establish the links.

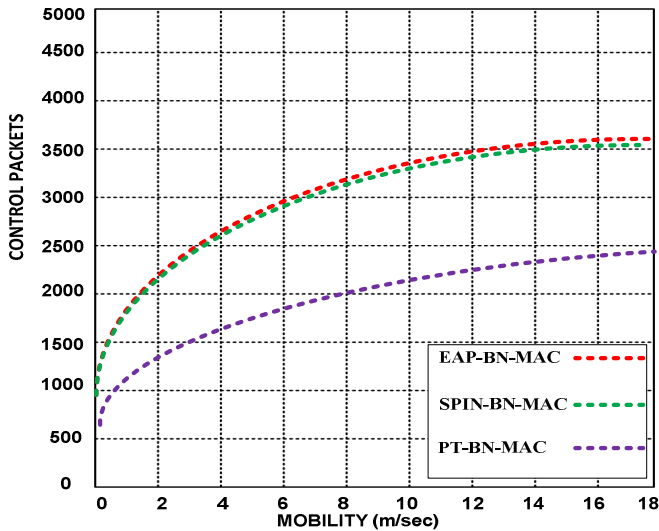


Figure 3. Control packets for PT, SPIN, and EAP for different numbers of nodes

B. Throughput

We evaluate the throughput performance of each routing protocol. PT appears to be compatible with BN-MAC. Figure 4 presents the results of simulations using EAP, SPIN, and PT with BN-MAC. To check the robustness of the three routing protocols, we simulate a scenario that involves static and mobile objects. The speeds of the sensor nodes vary from 0 to 18 meters/second.

The simulations validate that BN-MAC with PT produces a stable throughput, whereas SPIN and EAP with BN-MAC face slight problems due to motion. As a result, SPIN and EAP have reduced the throughputs. The simulation results demonstrate that PT with BN-MAC is the superior choice for several WSN applications. BN-MAC-EAP and BN-MAC-SPIN result in reduced throughput because both lack mobility features and consume additional time during route discovery and while maintaining the links.

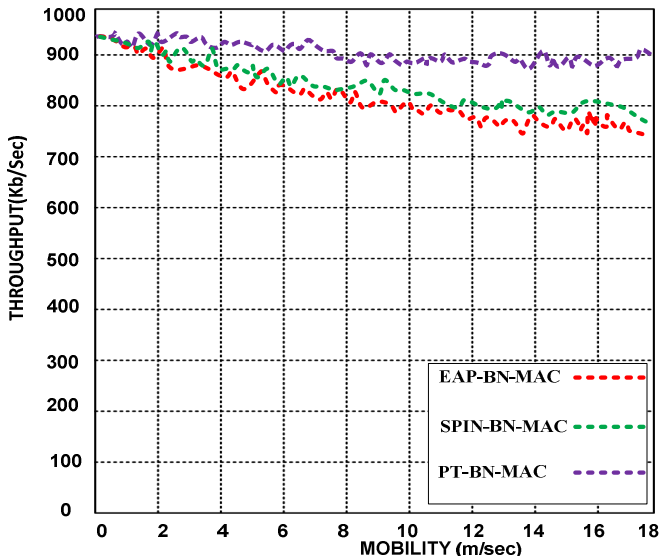


Figure 4. Throughput of BN-MAC-PT, BN-MAC-SPIN and BN-MAC-EAP on different mobility rates

V. CONCLUSION

In this paper, a scalable and a mobility-aware pheromone termite (PT) model is presented to provide robust and faster routing over WSNs. The model supports single and multiple paths over WSNs. Two important features which are packet generation rate and pheromone sensitivity are analytically discussed. BN-MAC-PT is compared with BN-MAC-EAP and BN-MAC-SPIN using ns2 simulator to analyze the strength of PT analytical model.

The simulation results demonstrate that BN-MAC-PT is a superior choice for mobility and scalability where it achieves 15-20% higher throughput at different mobility rates. In addition, PT-BN-MAC sends 22-27% less control packets as compared with other routing protocols. As a result, each node saves 13-18% energy.

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