Dynamic Power Control On-demand Routing Protocol

E. O. Ochola, D. Chatelain and A. Kurien

Abstract— **Power control for mobile Ad hoc networks has received an increasing research interest in recent years. Routing is one of the major sources of power consumption in mobile nodes. In particular, consumption is significantly high when Ad hoc routing is employed as nodes are assigned additional operations to support the routing of packets from other nodes. In this paper, we optimise transmission power in slow mobile Ad hoc networks to reduce power consumption. This is adaptively and deterministically achieved by arriving at the optimum transmission power between every two nodes within the transmission range of each other (neighbors), without use of heuristic safety factors. We simulate an Ad hoc On-demand Distance Vector routing (AODV); and provide an optimum transmission power aware routing algorithm for mobile Ad hoc network. The on-demand algorithm sends out request for routes to the destination only if the source has data packet(s) to transmit and does not maintain routes that are not in active communication. Simulation results show that our scheme improves energy efficiency for AODV routing protocol leading to a considerable reduction in total power consumption to route a packet from source to destination node.**

Index Terms— **Ad hoc networks, AODV, OMNeT++, optimum transmit power and routing.**

I. INTRODUCTION

AN Ad hoc wireless network is a multihop self-configuring wireless network where there is cooperative engagement of wireless nodes without intervention from a centralized access point. Unlike cellular networks where base stations simplify routing and resource management, Ad hoc wireless networks require routing and resource management to be done in a distributed manner in which all nodes coordinate, to enable communication among them. By implication each node in an Ad hoc network must be intelligent enough to function both as a network host for transmitting and receiving data and as a network router for routing packets from and to other nodes. If two nodes are not within radio range, all communication between them must pass through one or more intermediate nodes that act as routers. In mobile Ad hoc networks, the nodes are free to move randomly. Thus, the network topology may change dynamically. Therefore routing protocols must be able to find current optimal power consuming paths (sequences of intermediate nodes leading to a destination) in such dynamic conditions.

On-demand protocols that initiate routing activities on an on-demand basis have been widely studied because of their low routing overhead. Well-known on-demand protocols are AODV (Ad hoc On-demand Distance Vector protocol) [1], [14] and DSR (Dynamic Source Routing protocol) [2], [14]. Although AODV outperforms DSR in many cases [3], AODV packets are transmitted at a common maximum power (P_{max}) which is a considerable loss on power consumption. Intuitively, when two node pairs are close to each other, only a low transmission power may be required to have them communicate with each other. Transmitting packets at high power level in such a case may generate too much interference to the network and consume more power than necessary. Therefore, the determination of an appropriate transmission power for each packet needs to be considered, which is referred to as transmission power control. The power level should be high enough to guarantee the transmission and should be low enough to provide power saving. To avoid such power loss, several studies such as [4], [5], [6], [7] [8] and [9] have been proposed that can extend AODV to compute packets' optimum transmission powers. They deterministically [4], [5], [6], [7] or adaptively [8], [9] compute the appropriate DATA transmit powers between two communicating nodes. This reduces the total power consumption in every chosen path during DATA forwarding from source to destination. However, [4] and [5] use a heuristic safety factor c(t) and may not work for certain scenarios, [6] and [7] may need extra hardware support and the noise power level estimation may not be accurate enough, [8] and [9] have the drawbacks on the rate of transmission power variation (too frequent or rarely) and how to determine the initial transmission power. On the other hand, most of the routing protocols for mobile Ad hoc networks are designed assuming symmetric links and routes. As a result, nodes are constrained to use a common power level. In this regard, distributed power control algorithms have been designed to choose the lowest common power level that keeps the network connected with symmetric bi-directional links, maximize the network capacity and minimize the energy consumption [10]. In the presence of node mobility, nodes may end up non-uniformly distributed [11] in space and even a single outlying node could force all the nodes to use a higher common power level. As a result, nodes cannot always operate

---

Manuscript received April 13, 2007.

E. O. Ochola is with French South African Institute in Electronics (F'SATIE), Private Bag X680, Pretoria 0001, South Africa (e-mail: oketchjapan@scientist.com).

D. Chatelain is with French South African Institute in Electronics (F'SATIE), Private Bag X680, Pretoria 0001, South Africa (e-mail: damien.chatelain@fsatie.ac.za)

A. Kurien is with Tshwane University of Technology, School of Electrical Engineering, Private Bag X680, Pretoria 0001, South Africa (e-mail: kurienam@tut.ac.za)

at a fixed common power level and frequent global coordination among nodes would be necessary to synchronize to a new common power level. Also, operating at the lowest common power level can introduce frequent route failures in the presence of node mobility. Frequent route repairs and global coordination for power control may increase the signaling overhead prohibitively. This could in turn have an adverse impact on the network power consumption. Hence, there is a need to develop localized power control strategies that can handle mobility.

This paper focuses on the power limitation problem in Ad hoc networks, specifically the considerations involved in obtaining the optimum packet's transmit power and finding the least power consuming path whenever multihop and multipath are involved between source and destination nodes.

The rest of the paper is organised as follows. In section II, we briefly illustrate the proposed algorithm operation. Section III describes the transmission power control. Section IV explains our simulation environment in OMNeT++ [12], presents the simulation results and interpret them. Conclusion of the main results and further research direction are presented in section V.

II. PROPOSED PROTOCOL OVERVIEW

In this section, the operation of the proposed algorithm is presented. Since the purpose of the algorithm is to improve power consumption of existing on-demand protocols (specifically AODV in this paper), the proposed algorithm description is based on AODV. The modifications for power optimisation are also introduced.

The AODV [1], [14] routing protocol is a reactive routing protocol; therefore, routes are determined only when needed. Fig. 1 shows the message exchanges of the proposed protocol.

HELLO messages are used to detect and monitor links to neighbors. Each active node periodically broadcasts more than one HELLO message at varied transmit power levels that all its neighbors receive. An acknowledgement (HELLO_ACK) containing optimum transmit power is sent back to every HELLO message initiator. Since nodes periodically send Hello messages, if a node fails to receive several Hello messages from a neighbor, a link break is detected.

When a source has data to transmit to an unknown destination, it sets a timer and broadcasts a Route Request (RREQ) for that destination. At each intermediate node, when a RREQ is received, a route to the source is created. If the receiving node has not received this RREQ before, it is not the destination and does not have a current route to the destination, it rebroadcasts the RREQ. If the receiving node is the destination or has a current route to the destination, it generates a Route Reply (RREP). The RREP is unicast in a hop-by-hop fashion to the source. As the RREP propagates, each intermediate node creates a route to the destination. When the source receives the RREP, it records the route to the destination and can begin sending data. If multiple RREPs are received by the source before its timer expiry, the route with the least power consumption is chosen.

As data flows from the source to the destination, each node along the route relays the data packet at optimal power to its neighbor in the next-hop and updates the timers associated with the routes to the source and destination, maintaining the routes in the routing table. If a route is not used for some period of time, a node cannot be sure whether the route is still valid; consequently, the node removes the route from its routing table.

If data is flowing and a link break is detected, the detecting node retransmits the data at P_{max} before a Route Error (RERR) is sent to the source of the data in a hop-by-hop fashion incase of further breakage. As the RERR propagates towards the source, each intermediate node invalidates routes to any unreachable destinations. When the source of the data receives the RERR, it invalidates the route and reinitiates route discovery if necessary.

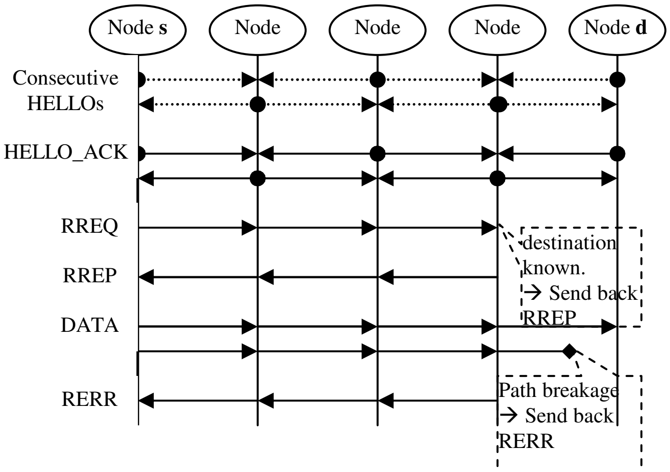


Fig. 1. Proposed protocol messaging.

III. TRANSMIT POWER CONTROL

In the proposed routing algorithm, nodes learn of their neighbors by broadcasting 'HELLO' packets and updating their routing table upon receipt of the HELLO acknowledgements (HELLO_ACKs). It is at this point when the nodes determine the optimum transmission power on a per-packet basis to their neighbors, both adaptively and deterministically based on the HELLO-HELLO_ACK relationship. The HELLO_ACK packets are transmitted at P_{max} and contain additional information on the optimum transmission power between every two communicating nodes which is to be considered for use during DATA packet transmission. The RREQ packets' transmit powers are also set to P_{max}. This helps a great deal in route discovery. The source node is capable of discovering as many routes as possible to their destination due to long transmission ranges giving room for the selection of the least power consumption route. The destination and the packet relaying nodes transmit their control packets at P_{max}. This reduces the probability of DATA packet retransmissions due to none-received DATA acknowledgements (DATA_ACK) resulting from low transmit power assigned for their transmissions. Hence, a reduction in power consumption and an increased throughput is obtained.

A. *Discrete Adaptive Transmit Power Optimization*

This approach determines the value of optimum transmission power adaptively by broadcasting more than one HELLO packet during neighbors' discovery at successively reduced transmit power and the HELLO_ACK from the neighbors containing the transmit power of the last HELLO packet received correctly.

In this paper, five HELLO packets are consecutively transmitted before the HELLO_ACK can be received. The transmission power of the HELLO packet is decreased from the P_{max} in a stepwise manner. The five successively broadcasted HELLO packets are arbitrarily assigned the following transmission power percentages of the P_{max} as shown in Table I below.

Table I. Discrete transmit power levels

HELLO packet	1st	2nd	3rd	4th	5th
P_t	100% i.e P_{max}	74%	54%	38%	26%

When a node receives a HELLO packet, it starts a timer to listen to the maximum possible number of HELLO packets from each specific neighbor. This can go to a maximum of five HELLO packets. On expiry of the timer duration, it sends back to the HELLO packet sender a HELLO_ACK with the last transmit power of the HELLO packet it received attached to the additional optimal transmit power field. Finally, the HELLO_ACK receiving node updates its routing table with the optimal power received to be used during data transmission. A scenario of the HELLO process is described in Fig. 2.

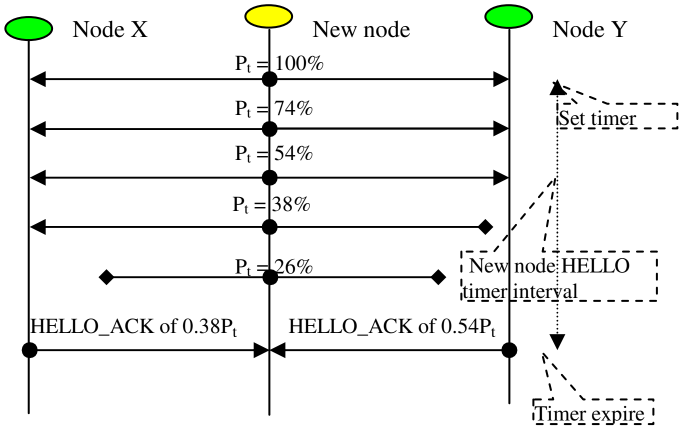


Fig. 2. Adaptive optimal power HELLO process

B. *Associative Deterministic Transmit Power Optimization*

The relationship between the necessary transmission power for HELLO and HELLO_ACK is determined. Given the transmission power (P_t) of HELLO packet, the equation to calculate the appropriate transmission power for HELLO_ACK to let it be received correctly, is derived.

A network with sender *X* and receiver *Y* is considered. The distance between them is *d*. *X* sends a HELLO to *Y* and *Y* replies with a HELLO_ACK back to *X*. The *transmission power* of packet *x* at location *t* is defined as $Pt_{x,t}$. For example, $Pt_{HELLO,X}$ denotes the *transmission power* of HELLO from sender *X* and $Pr_{HELLO,Y}$ denotes the *received power* of HELLO at node *Y*. $R_{x,t}$ defines the transmission range of packet *x* from transmitter *t*.

Assume that the channel propagation model is a *two-ray ground model* [13], [14]. The received power at a distance *d* from the transmitter can be expressed as follows.

$$P_r = \frac{P_t * G_t * G_r * h_t^2 * h_r^2}{d^4} \qquad (1)$$

The relationship between transmission power of HELLO, HELLO_ACK and the received power of HELLO and HELLO_ACK in the intersection region in Fig. 3, is then derived. Here, P_{ave} and R_{ave} denote the average transmission power and the average transmission range respectively. It follows that, for the classical AODV protocol which uses constant transmission power, usually the maximum transmit power, P_{ave} is always equal to P_{max} while R_{ave} equals to R_{max}.

Considering (1) and assuming that G_t, G_r, h_t^2 and h_r^2 are all normalized for ease of analysis, the following expressions are then derived from Fig. 3.

$$Pr_{HELLO,Y} = Pt_{HELLO,X}/d^4 \qquad (2)$$
$$Pr_{HELLO\_ACK,X} = Pt_{HELLO\_ACK,Y}/d^4 \qquad (3)$$
$$R^4_{HELLO,X} = Pt_{HELLO,X}/Rx_{threshold} \qquad (4)$$
$$R^4_{HELLO\_ACK,Y} = Pt_{HELLO\_ACK,Y}/Rx_{threshold} \qquad (5)$$
$$R^4_{ave} = P_{ave} / Rx_{threshold} \qquad (6)$$
$$gain(X,Y) = Pr_{HELLO,Y}/Pt_{HELLO,X.} \qquad (7)$$
$$gain(Y,X) = Pr_{HELLO\_ACK,X}/Pt_{HELLO\_ACK,Y.} \qquad (8)$$

Where $Rx_{threshold}$ is the minimal necessary power level to receive a packet correctly (the received power level at the boundary of the transmission zone), (4) and (5) are the definitions of the transmission radius of HELLO and HELLO_ACK respectively, (6) is the definition of the average transmission radius, (7) and (8) are the definitions of the channel gain between the sender and the receiver.

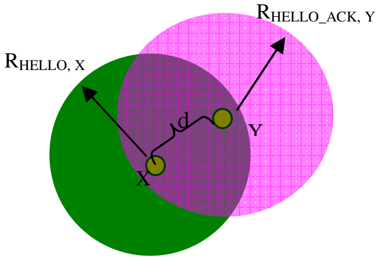


Fig. 3. HELLO-HELLO_ACK relationship

In order to receive HELLO_ACK correctly, the transmission power of HELLO and HELLO_ACK should fulfill two requirements, namely the path loss constraints and the signal to interference constraint. This implies the following based on the first requirement.

$R_{HELLO,X} \geq d$

$R_{HELLO\_ACK,Y} \geq d$

The second requirement implies the following.

$$Pr_{HELLO\_ACK,X} \geq \overline{P_{noise,X}} * SIR_{threshold}$$

$$Rx_{threshold} = SIR_{threshold} * \overline{P_{noise,X}} \qquad (9)$$

Where $SIR_{threshold}$ is the signal to interference ratio (SIR) threshold and $\overline{P_{noise,X}}$ represents the maximal noise power level at node *X* when *X* receives HELLO_ACK. $R_{HELLO,X}$ is fixed to R_{max} to notice as many neighbors as possible. This is simply achieved by transmitting the packet with maximum transmit power. The appropriate optimal transmit power for the HELLO_ACK from node *Y* to be received correctly at node *X*, is then determined. This requires the knowledge of the noise at node *X* ($\overline{P_{noise,X}}$) which is derived in the following subsection.

(i) $\overline{P_{noise,X}}$ Derivation

We designate $\overline{P_{noise,X}}$ to be the worst case average noise level. That is, all other nodes outside node *X*'s transmission range, are active leading to maximum interference (noise).

The transmitters are bound by several constraints; all nodes transmit packets at a power level of P_{ave} in situations where transmit powers are assigned different values at different nodes, and no transmitter can be within the transmission range of another active transmitter. Based on the constraints, each transmitter is separated from each other with at least a distance of R_{ave} which is the average transmission range. When a node is within other node's transmission zone, it is note allowed to transmit a packet according to the rule of IEEE802.11 MAC standard. Then $\overline{P_{Noise,X}}$ defines the maximal value of the noise at node *X* when the network status is steady. The density of transmitters, that is, the number of transmitters within unit space, in this case is smaller than $1/R_{ave}^2$. $\overline{P_{Noise,X}}$ has the following constant.

$$\overline{P_{Noise,X}} = \int_{R_{HELLO,X}}^{\infty} \frac{P_{ave}*2*\pi*x}{R_{ave}^2*x^4}*dx \qquad (10)$$

The above expression's limits are between $R_{HELLO,X}$ and ∞ since the interfering transmitters (active nodes) are only possible to exist outside the transmission range of the $R_{HELLO,X}$ to infinity according to our assumption.

(ii) Determination of Optimum Transmission Power (P_{opt}) for $Pt_{HELLO\text{-}ACK,Y}$

The transmission power constraints to guarantee the correct reception of HELLO and HELLO_ACK are as follows.

$$Pt_{HELLO,X} \geq Rx_{threshold}/gain(X,Y) \qquad (11)$$

$$Pt_{HELLO\_ACK,Y} \geq Rx_{threshold}/gain(Y,X) \qquad (12)$$

It requires that the transmission power of HELLO and HELLO_ACK at receiver side be greater than or equal to the $Rx_{threshold}$ to guarantee the transmission of HELLO_ACK. So

$$Pr_{HELLO,Y} \geq Rx_{threshold} \qquad (13)$$

$$Pr_{HELLO\_ACK,X} \geq Rx_{threshold} \qquad (14)$$

Simplifying the above equations from 2 to 14, we have [15]

$$Pt_{HELLO\_ACK,Y} * \sqrt{\frac{Pt_{HELLO,X}}{P_{ave}}} \geq \frac{SIR_{threshold}*\pi*Rx_{threshold}}{gain(X,Y)}$$

This implies the following.

$$Pt_{HELLO\_ACK,Y} \geq \sqrt{\frac{P_{ave}}{Pt_{HELLO,X}}} * \frac{SIR_{threshold}*\pi*Rx_{threshold}}{gain(X,Y)} \qquad (15)$$

Similarly the associative requirement between HELLO_ACK and DATA ($Pt_{HELLO\_ACK,Y}$-$Pt_{DATA,X}$) for correct reception of DATA is obtained below.

$$Pt_{DATA,X} \geq Rx_{threshold}/gain(X,Y) \qquad (16)$$

The associative constraint between HELLO_ACK-DATA is then obtained as follows.

$$Pt_{DATA,X} \geq \sqrt{\frac{P_{ave}}{Pt_{HELLO\_ACK,Y}}} * \frac{SIR_{threshold}*\pi*Rx_{threshold}}{gain(Y,X)} \qquad (17)$$

The variable $\frac{SIR_{threshold}*\pi*Rx_{threshold}}{gain(X,Y)}$ is a constant in the case there is no mobility and can be calculated when $gain(X,Y)$ is known. The right-hand side of (15) and (17) are calculated after path loss factors gain(X,Y) and gain(Y,X) are estimated through direct substitutions in (11) and (12) path loss constraints. By exchanging packets between node pairs, each sender knows the attenuation gain between it and its corresponding receiver.

Because P_{ave} is not known in advance, we take the maximal possible value P_{max} for P_{ave} and let HELLO's transmission power always equals to P_{max}. Therefore, once P_{ave} and Pt_{HELLO} are known, we calculate the optimum transmission power of DATA according to the constraints (11), (12) and (16). Each node *X* transmits DATA packet to node *Y* at the power level of

$$\max\left(\frac{Rx_{threshold}}{gain(X,Y)}, \min\left(P_{\max}, \sqrt{\frac{P_{ave}}{P_t(Y,X)}}\frac{\psi*\pi*Rx_{threshold}}{gain(Y,X)}\right)\right),$$

where ψ is the $SIR_{threshold}$ and $P_t(Y,X)$ is the transmission power of the previous received packet in set of (HELLO and HELLO_ACK) from node *Y*.

C. Our Optimum Transmission Power for DATA Packets

Two possible optimum power computations using associative deterministic (*ass. det.* P_{opt}) and discrete adaptive (*disc. adap.* P_{opt}) approaches are obtained. It is chosen to transmit the DATA packet at the uppermost optimum transmission power value computed to the neighboring node in the next-hop along the selected route reply (RREP) which increases DATA delivery chance. That is;

$$P_{DATA} = \max\left(ass.\det.P_{opt}, disc.adap.P_{opt}\right)$$

The computed optimal power is used to ensure that the DATA packet is transmitted at almost the minimum necessary power to be received correctly by the node in the next-hop.

Any retransmissions of DATA packet as a result of a route error (RERR) is done at the maximum transmit power P_{max}. The retransmission process of DATA packet due to route error (RERR) is shown in Fig. 4.

IV. PERFORMANCE EVALUATION

The simulation setup is a 600 meter by 600 meter arena containing a set of 10 to 50 mobile randomly distributed nodes. Fig. 5 (b) shows a 50-node network generated by the OMNeT++ simulator during run-time in which all the nodes act as transmitters and receivers. The arrows denote the direction of the desired communication channel. The channel parameters are shown in Fig. 5 (a).

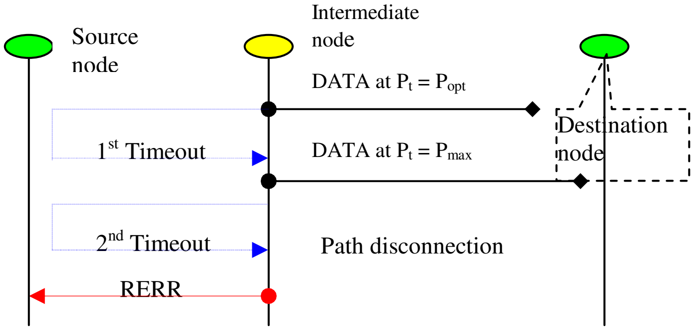


Fig. 4. DATA retransmission and RERR process

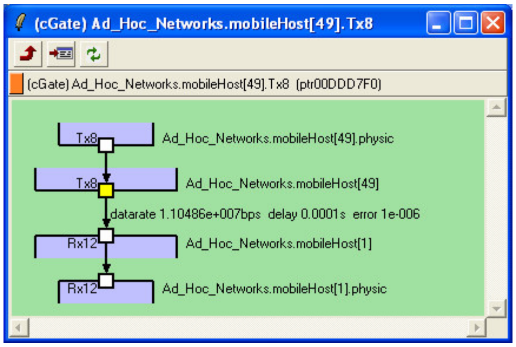
We evaluate the performance of the two routing algorithms (classical AODV with minimum hop routing and the proposed routing algorithm with optimum power consumption as routing metrics) for two different P_{max} in randomly–generated network topologies: the initial locations of the 10 to 50 wireless stations in the network are arbitrarily determined and each station can move in any direction with a speed of up to 5m/s for some time interval with a *Normal Walk Mobility* model. The source-destination pairs of nodes are randomly chosen. The performance metrics that we consider are the average power consumption per path, the average measured throughput, and the average latency. These metrics enable us to determine the influence and the utility of chosen parameters, which define the routing metric used.

The comparison results of data message throughput and average power consumption per routed packet are shown in Fig. 6(a) and (b) respectively. Fig. 6(b) shows the average transmit power that a packet consumes to get to its destination. Only the correctly delivered DATA packets are considered. The low average as the number of nodes increase is due to the higher probability of choosing a nearer destination node in a highly dense network. Fig. 6 (b). confirms the results in [10], whereby, assigning a common lower P_{max} reduces power consumption, in which our proposed Optimum Transmit Power algorithm (OTP-AODV) performs better. The ratio of throughput to power consumption in OTP-AODV is also better than [4]. The proposed protocol nearly maintains the delay achieved by the classical AODV as shown in Fig. 7 while reducing the network power consumption. Clearly, our proposed protocol performs the best. This is reasonable because the protocol is designed to be power efficient in transmitting data packets.

V. CONCLUSION

In this paper, a dynamic power control on-demand routing protocol for Ad hoc networks has been proposed. The classical AODV protocol which uses the shortest (least hops) path has been improved by both introducing procedures to determine the optimum transmission power levels on a per-packet basis for each neighbor, both adaptively and deterministically. The key idea is to enforce the HELLO/HELLO_ACK message before each data transmission, and then select the most power-efficient route for the subsequent data frame transmission. We compare data message throughput, average power consumption per routed packet and the average latency performances of the OTP-AODV, against the classical AODV. Simulation results show that our proposed algorithm consistently outperforms the classical AODV in most cases.

In future work, through the execution of many mobile network simulations, we will analyze the performance of the proposed optimum transmission power routing scheme with other existing on-demand routing protocols, in terms of efficiency in power consumption.



(cGate) Ad_Hoc_Networks.mobileHost[49].Tx8

(cGate) Ad_Hoc_Networks.mobileHost[49].Tx8 (ptr00DDD7F0)

Tx8 Ad_Hoc_Networks.mobileHost[49].physic

Tx8 Ad_Hoc_Networks.mobileHost[49]

datarate 1.10486e+007bps delay 0.0001s error 1e-006

Rx12 Ad_Hoc_Networks.mobileHost[1]

Rx12 Ad_Hoc_Networks.mobileHost[1].physic

Fig. 5 (a). A link channel between two mobile hosts (49 and 1 in this case) with channel parameters.

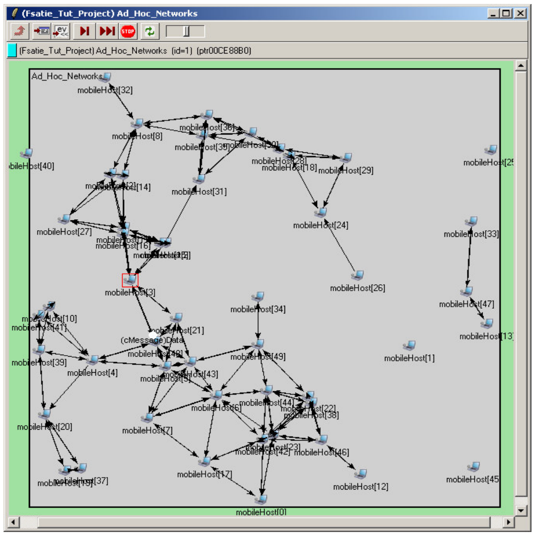


Fig. 5 (b). 50-node network example

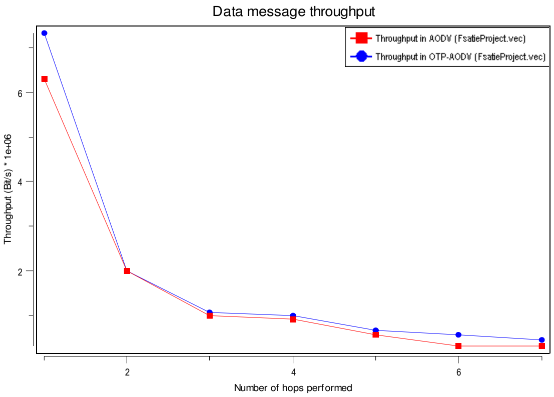


Fig. 6 (a). Average throughput

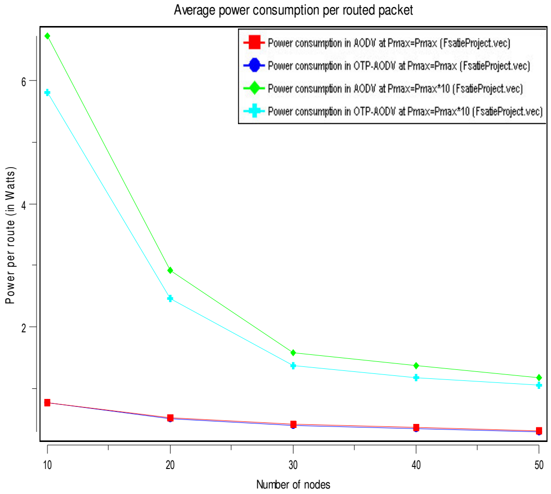


Fig. 6 (b). Power consumption at P_{max} and $P_{max}*10^1$

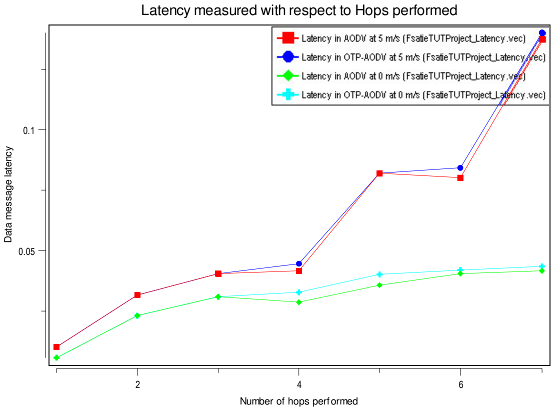


Fig. 7. Data message latency vs number of hops performed

REFERENCES

[1] C. E. Perkins, E. M. Belding-Royer, and S. Das. Ad hoc On-Demand Distance Vector (AODV) Routing. *RFC 3561*, July 2003.

[2] D. Johnson and D. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," In Mobile Computing, Vol. 353, ed. T. Imielinski and H. Korth, pp.153-181, Kluwer Academic Publishers, 1996.

[3] S. R. Das, C. E. Perkins, and E. M. Royer, "Performance Comparison of Two On-demand Routing Protocol for Ad Hoc Networks," Proc. of 19th IEEE Conf. on Computer and communications, pp.3-12, 2000.

[4] Eun-Sun Jung, Nitin H. Vaidya, "A Power Control MAC Protocol for Ad Hoc Networks," in *MOBICOM*, 2002, pp. 36-47.

[5] Alaa Muquattash and Marwan Krunz, "Power Controlled Dual Channel (PCDC) Medium Access Protocol for Wireless Ad Hoc Networks," in *INFOCOM*, April, Ed., 2003, pp. 470-480.

[6] Jeffrey P. Monks, Vaduvur Bharghavan and Wen-mei W. Hwu, "A Power Controlled Multiple Access Protocol for Wireless Packet networks," in *INFOCOM*, 2001, pp. 219-228.

[7] Shu-Lin Wu, Yu-Chee Tseng, and Jang-Ping Sheu, "Intelligent Medium Access for Mobile Ad Hoc Networks with Busy Tones and Power Control ," in IEEE Journal on Selected Area in Communications 2000, ser. 9 vol. 18, Sept. 2000, pp. 1647-1657.

[8] S. Agarwal, S. Krishnamurthy, R. Katz and S. Dao, "Distributed Power Control in Ad-hoc Wireless Networks," in *PIMRC* 2001, vol. 2, Oct. 2001, pp. 59-66.

[9] Seung-Jong Park and Raghupathy Silvakumar, "Load Sensitive Transmission Power Control in Wireless Ad-hoc Networks," in *GLOBECOM*, 2002.

[10] Narayanaswamy, S., Kwadia, V., Sreenivas, R. S., and Kumar, P. R. Power Control in Ad Hoc Networks: Theory, Architecture, Algorithm and Implementation of the COMPOW Protocol. *In Proceeding of European Wireless Conference*, (Feb. 2002).

[11] Bettstetter, C. The Node Distribution of the Random Waypoint Mobility Model in Wireless Ad Hoc Networks. *IEEE Transactions on Mobile Computing*, 2, 3 (July – Sept. 2003), 257 – 269.

[12] Andrias Vraga, OMNeT++, www.omnetpp.org.

[13] T. S. Rappaport. *Wireless communications, principles and practice*. Prentice Hall, 2004.

[14] C. Siva Ram Murthy and B. S. Manoj. *Ad Hoc Wireless Networks, Architectures and Protocols*. Prentice Hall, 2004.

[15] E. O. Ochola, D. Chatelain, A. Kurien and O. J. Oyedapo, "Optimum Transmit Power On-demand Routing Algorithm," in 14th IEEE International Conference on Telecommunication and 8th IEEE Malaysia International Conference on Communications, 14th-17th May, Penang, Malaysia 2007 [Telecommunication and Signal Processing].

E. O. Ochola received his B.Sci. in Computer Science honours degree from University of Egerton, Kenya, in 2004. He is currently pursuing a double masters degree in Electronic Engineering (M.Sci. in Electronic Engineering) and Electrical Engineering (M.Tech. Telecommunication Technology) degrees from *Ecole Supérieure d'Ingénieurs en Electronique et Electrotechnique (ESIEE),* France and *Tshwane University of Technology (TUT),* South Africa respectively. His research interests cover routing protocol development and power consumption management for Ad hoc networks.