Multi-Objective Cross-Layer Optimization with Pareto Method for Relay Selection in Multihop Wireless Ad hoc Networks

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Abstract: - The focus of this paper is cross layer optimization of relay selection on multihop wireless ad hoc networks. Cross-layer metrics that will be optimized are power consumption, throughput, and load balancing in wireless ad hoc networks for the outdoor and indoor configurations. Those three resources (performance indicators) are optimized using the multi objective optimization with Pareto method. The results obtained apply a dynamic ad hoc network model and optimization can be done simultaneously to all three resources which are optimized based on the route or path. Several alternatives in the relay selection are shown in the following simulation. The selection of the optimal relay can be based on one or a combination of the three performance indicators. The performance of the optimal relay selection in the field of POF (Pareto Optimal Front) is shown by the shortest Euclidean distance. The result of optimization for indoor and outdoor multihop ad hoc networks with three performance indicators is shown.

Key-Words: - Multi Objective Optimization, Cross Layer, Pareto Method, Relay Selection, Euclidean Distance, Multihop Wireless Ad hoc Networks, Performance Indicator, Outdoor and Indoor Configuration

1 Introduction

An ad hoc network is a set of nodes that communicate dynamically and do not have a fixed infrastructure. Each individual node can act as a source, relay, and destination. Those nodes have limited transmission range and battery capacity [1]. Thus, nodes communicating in ad hoc networks might require a relay or shall cooperate with another node which acts as relay.

Relay has been tested to be applied to WLAN-based access point networks where a node communicates with another through a third node in its path. The result is an increase in cell capacity, energy efficiency, and a reduction in emissions of electromagnetic fields [2]. In [3], Li examines the relay selection on multihop of ad hoc networks based on signal to interference plus noise ratio (SINR). This study has a low complexity but is very helpful in analyzing performance on multihop communication. A node's SINR is determined according to the previous node along the path to optimize the capacity of the channel. Bletsas et al in [4] proposes a distributed relay selection scheme where a user selects the best path of source-relay-destination out of many relays that may be based on the biggest channel gain. In [5], Huang et al examines relay selection based on the two auction mechanisms, the SNR auction and power auction, for the allocation of distributed resources. The expected outcome of the auction process is in the form of Nash Equilibrium. The results obtained are resources in the form of greater throughput in SNR auction than in the power auction. In the study reported in [1-5], the relay selection is based only on resources in the physical layer. Resources that lie outside the physical layer (higher layer) can also affect the relay selection. In other words, an exchange of resources from the physical layer and higher layer for relay selection is desired. This encourages the development of combined optimization of resources in the physical and higher layers, which is called cross-layer optimization.

Cross-layer optimization for relay selection has been performed by many researchers. Here we will clarify some researches which are related to and support this research. Shi et al in [6] examines ways to increase throughput in the communication pair of source and destination in an ultra wide band (UWB) based ad hoc networks. The increase of the throughput is based on cross-layer approach namely scheduling and power control in the data link layer and routing in the networks layer. Throughput is obtained from the optimization result using the reformulation linearization technique (RLT). In [7], Le and Hossain explains cross-layer optimization in cooperative communication system for the physical layer and networks in form of joint routing, relay selection, and power allocation to minimize power consumption in the networks. It is subsequently expanded with the addition of congestion control to optimize the traffic and look for a power tradeoff (compromise) in the system. The method used is convex optimization with the Lagrange optimization technique. In [8], Chen et al performs cross-layer based optimization in the cooperative communication system of the relay selection. The resources which are optimized are energy efficiency and load balancing. Energy efficiency is obtained based on the duration of time while load balancing is applied to each node so that each node uses the same energy. For a stationary node which acts as relay, it turns out that energy efficiency and load balancing can not be achieved simultaneously. In order to solve this problem, multi-state cooperative is used. The energy efficiency of the node is performed to optimize the throughput and outage probability. Optimization is performed with convex optimization in Kurash-Kuhn-Tucker (KKT) condition. Ding et al in [9], discusses the cross-layer optimization in the form of joint routing, relay selection, and dynamic allocation of frequency spectrum to maximize throughput. The research was conducted for ad hoc networks of cognitive radio and optimization was performed with convex optimization. In the study reported in [6-9], the relay selection is performed by cross-layer optimization to improve resources performance. Since cross-layer optimization of relay selection involves a compromise of multiple objectives, some of which are contradicting each other, it is appropriate to adopt multi-objective optimization (MOO) approach [10].

In [11], Karkkainen et al examines mobile terminal which will be able to communicate with service providers using multiple networks connections. Each network connection has a various transmission speed and values. In selecting a networks connection, the problems, which are time and cost, are formulated into MOO. Both problems are solved using the scalarization method. Settlements used are the weighting method, neutral compromise solution, and the achievement of scalarizing function. Baynast et al in [12], examines cross-layer optimization for radio multicarrier system in the automatic repeat request (ARQ) based cognitive radio networks. There are four optimized problems namely packet error rate (PER), power consumption, throughput, and delay. The four issues are formulated into a scalar form. Furthermore, the settlement is performed using weighted sum approach and genetic algorithm. Elmusrati et al in [10], discusses radio resource scheduling (RRS) in the cellular communication system. RRS controls the radio resources, which are transmit power and data rate, to solve the problems by minimizing total transmit power, minimizing the outage, and maximizing throughput. These three problems are opposite, the two performance indicators should be minimized while the other one is maximized. Optimization is performed by merging the three problems into MOO. These three problems are formulated into scalarizing function and solved using weighted metric method. From studies in [10-12], MOO is solved using scalarization. In MOO with scalarization, the objectives can not be optimized separately because their solutions are dependent on one another. Later, in order to overcome this shortcoming, our study proceeds using MOO with the Pareto method.

Research using the Pareto method in solving the MOO problems in the field of wireless communication is still new. Initial studies initiated by Runser et al in [13], examines the application of the Pareto method in the solving of MOO problems in the wireless ad hoc networks. Three optimization problems are robustness, energy consumption, and delay. Initial results obtained are tradeoff characteristic of robustness, energy consumption, and delay for 2-hop ad hoc networks. This preliminary result becomes a motivation for the research reported in this paper, which is also to answer the lack of the research following [8] for wireless networks with relay.

In this study, our main contribution is first, optimization for dynamic ad hoc networks model that can be performed simultaneously for the optimized resources based on the route / path. Second, the optimization results are expressed in the Pareto optimal front (POF) in three dimensions and provide optimal performance of Pareto optimal solutions (POS). Third, it shows the optimization results for multihops ad hoc networks with indoor and outdoor scenarios with three performance indicators.

The rest of this paper is organized as follows. Section 2 provides an overview of ad hoc networks, radio propagation, and multiple problems optimization. Section 3 describes the model configuration, simulation parameter, and analysis of simulation results. Finally, the conclusions are presented in Section 4.

2 Problem Formulation

2.1 Wireless ad hoc networks

Wireless ad hoc networks can be described in a graph *G = (V, L),* where *V* = {1, 2, ... , *N* } is the set of nodes and *L* = {(1,2), (1.3), ... , (*N*-1, *N*)} is the set of links/hops. Ad hoc multihops networks contain pairs of nodes in communication involving other nodes as relays. A set of a number of links that form a multihop is called a path. If the number of total nodes (including source and destination) is *N*, then there are *(N*-2) 2-hop solutions, *(N*-2) *(N*-3) 3-hop solutions, *(N*-2) *(N*-3) *(N*-4) 4-hop solutions, and so on for the source and destination pair. In this study, the hop is limited to only three hops. Then every 3-hop solution is a path that is source-relay-relay-destination.

There are four methods of routing in ad hoc networks namely unicast routing, multicast routing, broadcast routing, and geocast routing [14]. In this study, broadcast routing is used where source transmits information to all nodes that each might serve as a relay so that the information arrives at the destination. Broadcast routing is chosen so that the transmitted data can be received by all the nodes next to them simultaneously so as to save time in the transmission.

2.2 Radio Propagation

2.2.1 Outdoor

It is assumed that each transmitter node can set the transmit power based on the feedback from the opposite node. Assuming that the transmitter and receiver antenna gain, Gt and Gr, are the same, and that the minimum power Pr received through the wireless channel specified, then the minimal transmit power consumption Pt required is:

$$Pt = k\ Pr\ d^{\alpha}\ 10^{-\frac{X_{\varphi}}{10}} \qquad (1)$$

with k denoting a multiplier constant, α representing the path loss exponent, and X_{φ} shadowing loss (dB) which is normally distributed with standard deviation φ. In this study, the multiplier constant is valued unity and every link / hop has a different shadowing value.

2.2.2 Indoor

For indoor scenario, the nodes in the ad hoc networks are inside a room. The rooms are separated by walls that might attenuate signals. This causes transmission coefficient [15]. Power consumption of a node transmitting to other nodes in different room can be determined through equation (1) by enclosing the influence of the transmission coefficient into the following:

$$Pt = k\ Pr\ d^{\alpha}\ 10^{-\frac{X_{\varphi}}{10}}\ \frac{1}{\prod_{m=1}^{M} \Gamma_{(m)}^{2}} \qquad (2)$$

with Γ and M being the transmission coefficient of the wall and the number of walls, respectively.

2.3 Ad hoc Network Performance Indicators

2.3.1 Power Consumption

Power consumption in the path is the overall power required in transmitting data from source to destination through multiple relays in each path. For ad hoc networks with three hops, every path is composed of L = 3 links. Power consumption in a path number p for the outdoor and indoor conditions can be determined through the following equation :

$$Pt_p = \sum_{i=1}^{L} Pt(i) \qquad (3)$$

While the optimal power consumption is the power consumption which has the smallest value of all path. The equation is as follows :

$$Pt_{opt} = \min\left(Pt_1, Pt_2, \ldots, Pt_{(N-2)(N-3)}\right) \qquad (4)$$

2.3.2 Throughput

Throughput in each link is the number of bits successfully transmitted in the link every second. For simplicity, the amount of throughput in this study can be represented by the value of channel capacity. Under a perfect condition, the value of the throughput approaches the channel capacity. Throughput value will be maximum if the reception power is also maximum for the constant bandwidth and noise power. The capacity can be calculated through the following equation [16] :

$$Th = W\ log_2\left(1+\frac{Pr}{N_0}\right) \qquad (5)$$

where W is the channel bandwidth and N_0 is the noise power. In this study, the noise that is affecting is the thermal noise and the noise power magnitude in each link/hop is considered constant.

The throughput for outdoor and indoor conditions depends on the magnitude of the outdoor and indoor maximum reception power. For ad hoc networks with three hops, the throughput in the path p can be determined through the following equation:

$$Th_p = \min\ (Th_1, Th_2, Th_3\ ) \qquad (6)$$

While the optimal throughput in an ad hoc networks in the path p-th is the maximum throughput of all paths which can be determined through the following equation:

$$Th_{opt} = \max\ \left(Th_1, Th_2, \ldots, Th_{(N-2)(N-3)}\right) \qquad (7)$$

2.3.3 Load Balancing

Load balancing, commonly referred to as fairness, is inversely indicated by the variance of some resources or performances [17]. In the wireless ad hoc networks, load balancing is very important because some nodes may have a better chance as a relay. If a node is used as a relay, the load of the node becomes:

$$B_i = B_{oi} + B_{di} \qquad (8)$$

where B_{oi} and B_{di} respectively are the traffic load of itself and the traffic load that leads to the i node.

After the load of each node is determined, the load balancing of each path can be reviewed based on the variance of the load of all nodes in the area with the following equation [17]:

$$Lb = \frac{1}{N}\sum_{i=1}^{N}\left(B_i - \left(\frac{1}{N}\sum_{i=1}^{N}B_i\right)\right)^2 \qquad (9)$$

From variances that occur in every path selection, the optimal path can be determined through the following equation:

$$Lb_{opt} = \min\ \left(Lb_1, Lb_2, \ldots, Lb_{(N-2)(N-3)}\ \right) \qquad (10)$$

2.4 Multi Objective Optimization

Optimization is the process of finding the best solution for optimization problems. For opposite problems, where the power consumption problem requires minimization, the load balancing problem needs minimization of load variance, while the throughput problem calls for maximization, the Pareto method can be used in finding the best solution. Mathematically the three problems can be written as follows [18]:

$$\begin{aligned}&\text{Min}\ \ Z_1 = f_1(Pt)\\&\text{Max}\ \ Z_2 = f_2(Th)\\&\text{Min}\ \ Z_3 = f_3(Lb)\\&\text{Subject to :}\\&\qquad Pr \geq P_{thd}\end{aligned} \qquad (11)$$

where P_{thd} is the threshold reception power.

Optimization with the Pareto method maintains the solution in the Pareto optimal front (POF) for the two problems separately during optimization. In POF, there is a dominance concept to differentiate dominated (inferior) and non-dominated solution (non-inferior). For the optimization of two problems, two non-dominated solutions can be described in plane POF (two dimensions). As for the optimization of three problems, the non-dominated solutions can be described in three-dimensional field POF [19]. POF of two problems, minimum and maximum, can be seen in Fig. 1 [20].

In determining the optimal value of a POF, the Utopia point should be determined first. The utopia point is the point in the objective space determined by the optimal value of each problem independently. After the Utopia point is determined, the optimal value can be determined by finding the shortest Euclidian distance [21].

The shortest Euclidean distance can be determined by the following equation [22]:

$$d_E = \min\sqrt{\left(\frac{Q_1 - Q_1^*}{Q_{1\,norm}}\right)^2 + \left(\frac{Q_2 - Q_2^*}{Q_{2\,norm}}\right)^2} \qquad (12)$$

where $\{Q_1^*, Q_2^*\}$ is the coordinate of the Utopia points, $\{Q_1, Q_2\}$ is the coordinate of POF points, and $\{Q_{1\,norm}, Q_{2\,norm}\}$ is the coordinate of the normalization points on the problem areas.

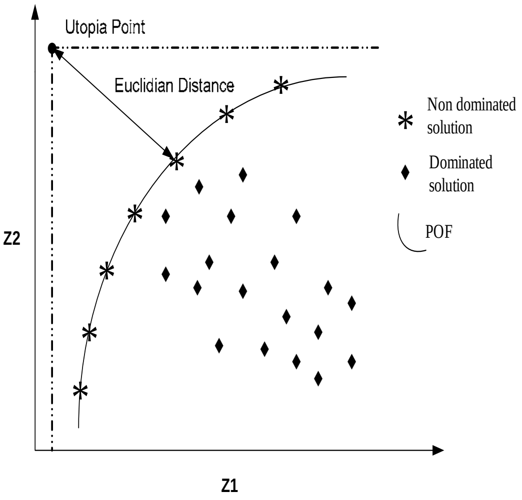

Fig 1. Pareto Optimal Front (POF) for Two Problems

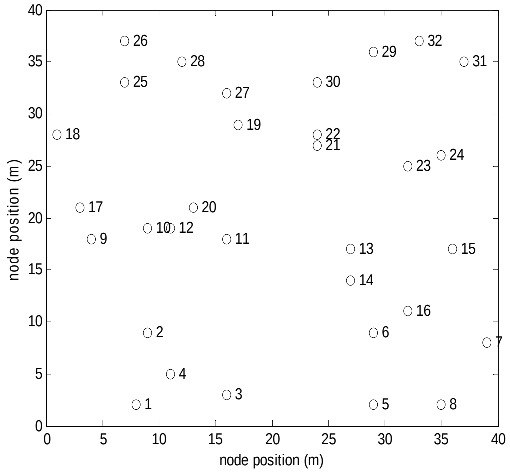

Fig 2. Outdoor Configuration

$Q_{1\,norm}$ is determined based on the minimum value of Q_1. Whereas $Q_{2\,norm}$ is determined based on the maximum value of Q_2.

3 Numerical Results

3.1 Model Configuration

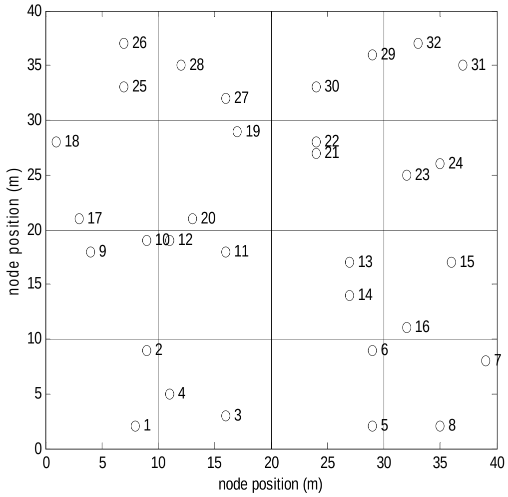

Fig 3. Indoor Configuration

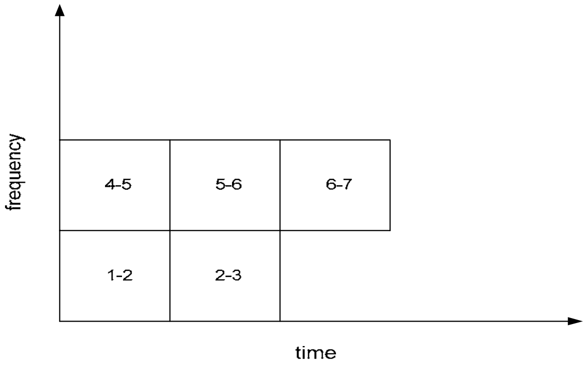

Fig 4. OFDMA Method

We consider ad hoc networks configurations working outdoors and indoors. Model for the outdoor condition can be seen in Fig 2. While the model for the indoor condition can be seen in Fig 3. In Fig 2, all nodes are in an open space of 40 m x 40 m. Meanwhile, in Fig 3, it is shown that the building area of 40 mx 40 m is divided into 16 rooms. Each room in the building is bounded by walls. Both configuration models have 32 nodes in random position.Node 1 serves as the source in our simulation, with node 32 as the destination, and the other nodes act as potential relays to form a three-hop ad hoc networks.

The protocol adopted by the system model can be described as follows:

- Source can identify the position of the destination. The process of identifying can be performed in a way that each node can detect other nodes through one hop and transmits the information to all nodes next to it in one hop [23].
- To avoid the occurrence of interference and collision between the nodes, the OFDMA (orthogonal frequency division multiple access) method is used in accordance with reference [24]. Each path uses different sub-carrier. While for each link in a path, different time slot is used. More details can be seen in Fig 4. In Fig 4, the frequency / sub-carrier and time slot division for both path 1-2-3 and 4-5-6-7 is shown.

Table 1 Parameters of Simulation

Parameter	**:**	**Value**
Outdoor path loss exponent , $\propto_o$	:	4
Indoor path loss exponent, $\propto_i$	:	2
Standard deviation of shadowing, φ	:	8 dB
Wall transmission coefficient, Γ	:	0,3
Threshold receive power, P_{thd}	:	- 50 dBm
Bandwidth, W	:	20 MHz
Noise, N_0	:	-101 dBm

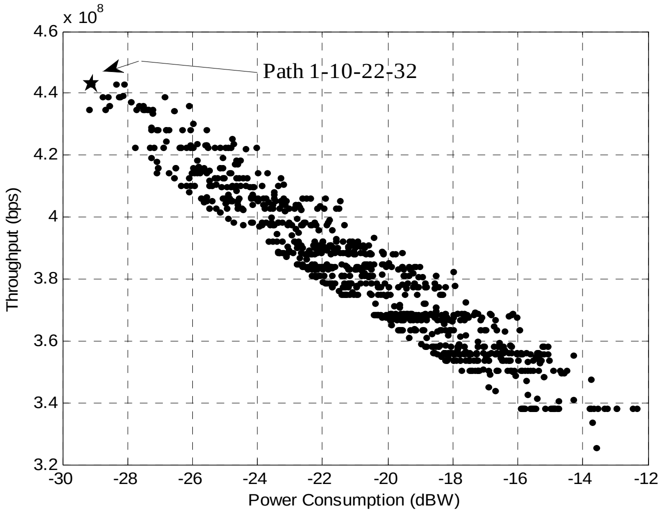

Fig 5. POF of Power Consumption and Throughput for Outdoor

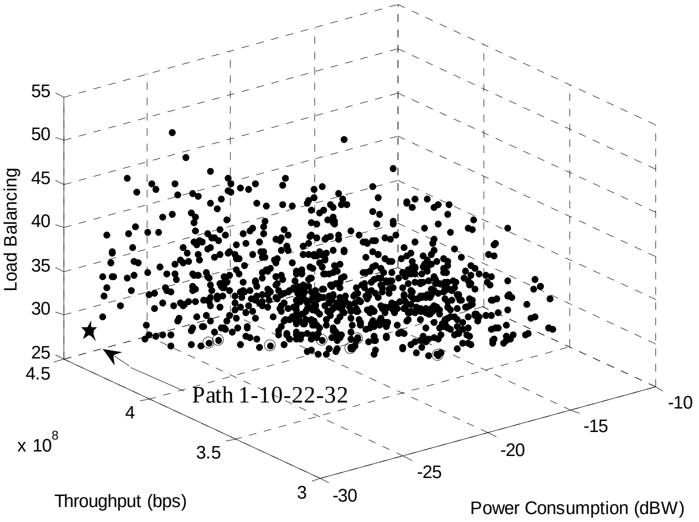

Fig 6. POF of Power Consumption, Throughput, and Load Balancing for Outdoor

Parameter values used in this simulation are taken based on the application of WLAN in wireless ad hoc networks shown in Table 1.

To evaluate the load balancing in this simulation, it is assumed that in addition to source that transmits the data to the destination, there are five nodes that transmit the data simultaneously to their respective destination nodes. As a result, there are multiple nodes that have a better chance as a relay. Those five nodes groups are assumed to be the path 4-12-29-32, 7-11-19-25, 10-19-22-23, 16-12-14-2 and 25-20-12-6. It is assumed that the sources, node 4, node 7, node 10, node 16, node 25 respectively can transmit the data at a rate of 5 Mbps, 3 Mbps, 8 Mbps, 7 Mbps, 2 Mbps and 11 Mbps respectively. While other nodes might be having a load of 2 Mbps, 7 Mbps, 12 Mbps and 17 Mbps. The loads of the nodes are scattered randomly.

3.2 Outdoor

Based on the power consumption, the optimal value is a path that has the minimum power consumption. Accordingly, path (1-11-22-32) with the normalized power consumption of -29.1821 dBW is selected.

As for the throughput, a path that has the maximum throughput is selected. There are three paths that have maximum throughput value. Those paths are (1-10-21-32), (1-10-22-32) and (1-10-27-32), each with throughput value of 443.21 Mbps.

Determining the optimal relay based on a single problem that is based on power consumption or throughput is relatively simple. If more than one problem and many searches for solution space are performed, determining the solution becomes difficult. Thus, Pareto optimization technique is required.

Optimization with Pareto methods leads to a trade-off between power consumption and throughput. Compromise for both problems can be seen in Fig 5, based on which the calculation for Euclidean distance is performed. The result is the shortest Euclidean distance of 0.0020 for path (1-10-22-32) which is marked by a star in Fig. 5, indicating that the optimal relay selected corresponds to path (1-10-22-32).

The existence of the load balancing value for outdoor condition causes the POF may be formed in three dimensions. Fig 6 shows that points marked by circles and star have the smallest value of load balancing of 27.7122. By taking these three resources into account, the selected optimal relay corresponds to path (1-10-22-32) because it has the shortest Euclidean distance of 0.0223 which is indicated by a star in Fig. 6.

3.3 Indoor

Based only on the power consumption, the optimal value is the path that has minimum power consumption. Accordingly, the path (1-12-22-32) with power consumption of -33.6347 dBW is selected.

As for the throughput value, a path that has a maximum throughput value is selected. The selected paths are (1-12-21-32) and (1-12-22-32) with a throughput of 674.98 Mbps.

Optimization with Pareto method causes a compromise between power consumption and throughput, as can be seen in Fig 7.

Based on Fig 7, the calculation for the Euclidean distance is performed. The result is the shortest Euclidean distance of 0 for path (1-12-22-32) which is symbolized by a star. Thus, the selected optimal relay is path (1-12-22-32).

The incorporation of load balancing into the optimization problem for indoor condition requires the POF to be formed in three dimensions. Fig 8 shows that points marked by circles and star have the smallest load balancing value of 27.7122. By taking these three resources into account altogether, the selected optimal relay is path (1-6-22-32) because it has the shortest Euclidean distance of 0.0804 which is marked by a star.

3.4 Discussion

Fig 5 shows that the POF results for outdoor conditions has scattered compromise values, while for indoor conditions Fig.7 shows a tendency of clustered compromise value to converge toward the Utopia point. This is due to the presence of several relays for indoor conditions which have similar power consumption value but have different throughput values. One possible explanation is that nodes in one room appear to experience similar total wall attenuation with respect to each of those in other rooms due to the same number of intervening walls, and further, the total wall attenuation experienced by these nodes differs from that experienced by nodes in other rooms.

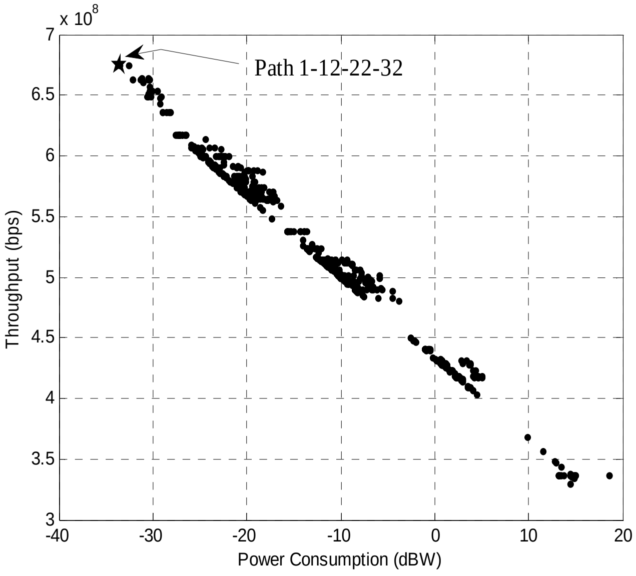

Fig 7. POF of Power Consumption and Throughput for Indoor

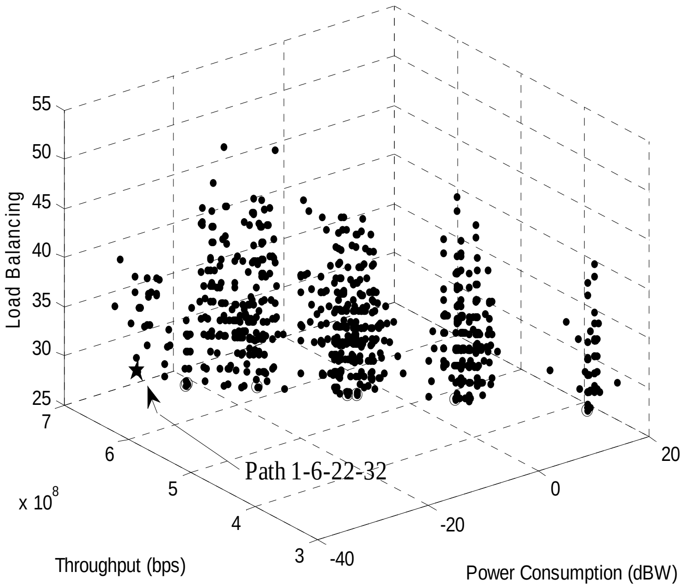

Fig 8. POF of Power Consumption, Throughput, and Load Balancing for Indoor

The optimal relay selection in two dimensional POF (of Fig 5 and Fig 7) for the two conditions used to form a multihop networks is the sequence of relays which approaches a straight line between the source and destination, and the distance of which between the source-relay-destination is approximately equal. With the presence of load balancing in the optimization problem (see Fig 6 and Fig 8), the optimal relay selection might change so it does not form a straight line because the nodes positioned at a straight line are more often used as a relay so that the load balancing variance is high.

Based on Fig 5 and Fig 7, the power consumption for indoor condition is greater than for outdoor. There are even some indoor paths which have more than 0 dBW. For example, the power consumption of 18.6 dBW makes path 1-31-3-32 not a realistic choice because the ad hoc terminal has a little battery power and hence the relay selection is extreme/not appropriate. This might happen due to the walls that reduce the power of the signal penetrating through them.

But based on Fig 5 and Fig 7, in optimal condition, the power consumption for outdoor condition is greater than for the indoor condition, while the throughput on the conditions outside the building is smaller compared to the conditions in the building. This is because the path loss exponent for outdoor is assumed to be 4, greater than that assumed for indoor which is 2.

In load balancing, if the load of the nodes that will act as a relay has less variations, the number of alternative paths will be greater, and vice versa, if the variations are more, the alternative paths will be fewer.

4 Conclusion

This paper has described the application of MOO technique with Pareto method for three performance indicators namely power consumption, throughput, and load balancing. The performance of the optimal relay selection in the field of POF for outdoor and indoor conditions is indicated by the shortest Euclidean distance. From the analysis of the simulation results, three conclusions can be made . First, it is found that the result of two-dimensional POF for outdoor condition has scattered compromise values while for indoor condition, the compromise values tend to converge toward the Utopia point. This is caused by the presence of some relays having similar power consumption value but have different throughput values. Secondly, for outdoor condition, all the nodes can act as a relay pairs, while for the indoor condition, the nodes must be accurately selected as relay pairs as there are some node pairs which do not qualify as relay. Third, the result of the three-dimensional POF shows that for outdoor condition, it has a scattered compromise values while for the indoor condition, it looks like clusters due to the same number of attenuating walls experienced by links to nodes in the same room.

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References:

[1] D. D. Perkins, H. D. Hughes, and C. B. Owen, “Factors Affecting the Performance of Ad Hoc Networks,” *Proceedings of the IEEE International Conference on Communications (ICC)*, pp.2048-2052, 2002.

[2] M. Kubisch, S. Mengesha, D. Hollos, H. Karl, and A. Wolisz, “Applying ad-hoc relaying to improve capacity, energy efficiency, and immission in infrastructure-based WLANs,” *Proc. of Kommunikation in Verteilten Systemen*, Leipzig, Germany, 2003.

[3] X. Edward Li, “Hop Optimization and Relay Node Selection in Multi-Hop Wireless Ad-hoc Networks,” *LNCS Social Informatics and Telecommunications Engineering,* Vol. 2, pp 161-174, 2009.

[4] A. Bletsas, A. Lippman, and D. P. Reed, “A Simple Distributed Method for Relay Selection in Cooperative Diversity Wireless Networks, based on Reciprocity and Channel Measurements,” *Proceedings of the IEEE Vehicular Technology Conference Spring*, Stockholm, Sweden, 2005

[5] J. Huang, Z. Han, M. Chiang, and H. V. Poor, “Auction-Based Resource Allocation for Cooperative Communications,” *IEEE Journal on Selected Areas in Comm*. vol. 26, no. 7, 2008.

[6] Y.Shi, Y.T. Hou, H. D. Sherali, and S. Kompella, “Cross Layer Optimization for UWB-Based Ad hoc Networks,” *Military Communications Conference (MILCOM)*, pp. 1-7, 2006.

[7] Le, L., and Hossain, E., (2008), Cross layer optimization frameworks for multihop wireless network using cooperative diversity, *IEEE Trans. On Wireless Communication*, vol. 7, no. 7.

[8] W. Chen, L. Dai, K. B. Letaief, and Z. Cao, “A Unified Cross Layer Framework for Resource Allocation in Cooperative Networks,” *IEEE Transc. on Wireless Communications*, vol. 7, no. 8, 2008.

[9] L. Ding, T. Melodia, S. N. Batalama, and J. D. Matyjasy, “Distributed Routing, Relay Selection, and Spectrum Allocation in Cognitive and Cooperative Ad Hoc Networks,” *Proceedings of the Seventh Annual IEEE Communications Society Conference on*

Sensor, Mesh and Ad Hoc Communications and Networks, Boston, 2010.

[10] M. Elmusrati, H. El-Sallabi,and H. Koivo, "Applications of Multi-Objective Optimization Techniques in Radio Resource Scheduling of Cellular Communication Systems," *IEEE Transc. on Wireless Communication*, vol. 7, no. 1, 2008.

[11] A. S. Karkkainen, K. Miettinen, and J. Vuori, "Best Compromise Solution for a New Multiobjective Scheduling Problem," *Elsevier : Computers & Operations Research* vol. 33, pp 2353–2368, 2006.

[12] A. de Baynast, P. Mahonen, and M. Petrova, "ARQ-Based Cross Layer Optimization for Wireless Multicarrier Transmission on Cognitive Radio Networks," *Elsevier : Computer Networks* vol. 52, pp 778–794, 2008.

[13] K. J. Runser, C. Comaniciu, and J. M. Gorcey, "A Multiobjective Optimization Framework for Routing in Wireless Ad Hoc Networks,"*IEEE International Symposium on Conference Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt)*, 2010.

[14] R. Ranjan Roy, "*Handbook of Mobile Ad hoc Networks for Mobility Models*," Springer, London, 2011.

[15] W. Honcharenko, H. L. Bertoni, , and J. Dailing, "Mechanisms governing propagation between different floors in buildings," *IEEE Transc. On Antennas and Propagation*, vol. 41, no. 6, 1993.

[16] T. S. Rappaport, "*Wireless Communication Principles and Practice*," Prentice-Hall, USA, 2002.

[17] Wong, J.W., Sauve, J.P., and Field, J.A., (1982), A Study of Fairness in Packet Switching Networks, *IEEE Transactions on Communications*, vol. 30, no. 2.

[18] M. Ehrgott, "*Multicriteria Optimization*," Springer, Germany, 2005.

[19] F. Pernodet, H. Lahmidi, and P. Michel, "Use of Genetic Algorithms for Multicriteria Optimization of Building Refurbishment, "*Eleventh International IBPSA Conference*, Glasgow, Scotland, 2009.

[20] E. K. P. Chong, and S. H. Zak, "An Introduction to Optimization," Third Edition, John Wiley & Sons, USA, 2008.

[21] T. Ozcelebi, , *Multi-Objective Optimization for Video Streaming*, PhD Thesis, Graduate School of Sciences and Engineering, Koc University, 2006.

[22] B. E. Cohanim, J. N. Hewitt, and O. de Weck, "The Design of Radio Telescope Array Configurations using Multiobjective Optimization: Imaging Performance versus Cable Length," *The Astrophysical Journal Supplement Series*, Volume 154, Issue 2, pp. 705-719, 2004.

[23] S. Capkun, M. Hamdi, and J. P. Hubaux, "GPS-free positioning in mobile Ad-Hoc networks," *Proceedings of the 34th Hawaii International Conference on System Sciences*, 2001.

[24] M. Salem, A. Adinoyi, M. Rahman, H. Yanikomeroglu, D. Falconer, Kim Young-Doo, E. Kim, Y. C. Cheong, "An Overview of Radio Resource Management in Relay-Enhanced OFDMA-Based Networks, *IEEE Communications Surveys & Tutorial*, vol. 12, no. 3, 2010.

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