Routing Protocol Metrics for Wireless Mesh Networks

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Abstract. Wireless Mesh Networks (WMNs) play an important role in today communication and they could take more portion of wireless communication in near future. WMN's research area challenges on some problems such as low throughput and high delays. Routing Protocols in WMNs have a vital role in data communication and the main key in all routing protocols is metric. In this paper, most of the metrics in WMNs are considered in different categories. Link-quality and Load-dependant metrics are covered most of the metrics and then later metrics for multi channels networks are considered. Expected Transmission Count (ETX) as a famous link-quality metric with all its divisions have been studied and then more metrics which consider more wireless parameters such as intra and inter interferences have been added. In the last sections, some metrics which provide for multi channel networks and multi interface devices are mentioned and also metric for cognitive radio environment. In the end of the paper, conclusion with a comparison table has been provided to compare metrics in WMNs.

Keywords: WMN. *Metrics, ETX, Link-quality metrics, load-dependent metrics, Multi channel metrics*.

1. Introduction

Wireless mesh networks consist of wireless nodes in an area that all nodes may not be in the transmission range of each other and some nodes which are going to send information to another node that it is outside the radio frequency coverage needs to use intermediate nodes to act as routers to receive the information and resend them to other nodes to reach in destination. Routing protocol plays a key role to have appreciable performance and the major part of each routing protocols is link metric [1]. The metrics that are used in wired networks cannot be extended to wireless networks for the reasons that wireless links often have more packets lost than the wired network and also in addition the wireless nodes use medium as a non exclusive media and all neighbours could make interference to the communication channel and it makes the throughput performance be less than wired network [2].

Hop count is the traditional, most popular metric in WMNs. It is simple to be calculated by devices but it does not take to the account the link quality and it is not accurate enough [3]. To improve metrics in routing protocols, more parameters have taken to the calculation to find the best path such as interface's bandwidth or path's delay. They calculate the link quality in more accurate way. This kind of routing metrics categorizes as link-quality metrics such as ETX, Expected Transmission Time (ETT), or *Effective Number of Transmission* (ENT).

The radio communication range is often unpredictable and the property of radio channel between nodes is not stable during the time period. Background noise, obstacles, channel fading and interference are causes that the channel qualities often vary [3]. Schmitz et al, show the influence of the wireless channel changes over the topological variations is more significant than the nodes mobility in a real environment [4][5]. They found that transmission interference behaviour is highly dependent upon the wireless link loss rates [4][5]. Interference could be intra-path interference wherein transmissions on different links in a path interfere on other links and inter-path interference is result of transmission on links in other paths. In Load-dependant metrics [6], the best route is selected based on the estimation of traffic load on nodes which participant in the route while link-quality metrics [6] choose the best route based on quality of the links through the route. Two main objects make quality based routing metrics work with better performance than the tradition ones, firstly, the links with higher bit rates have more efficiency than the links with lower bit rates and secondly nodes which are involved with congestion and collision which make the their media busy have less performance than the other nodes that their mediums are quiet. Some newly proposed metrics such as Expected Link Performance (ELP), Exclusive Expected Transmission Time (EETT) and **E**xpected **T**hrough**p**ut (ETP) have more suffusion performance to find the quality paths than the link quality metrics. They could consider link quality and also monitor the network for inter and intra interference to recognize busy links and bottle neck in the network and avoid using them to sending packets to destinations.

To increase wireless capacity in the network, two approaches could be selected. Firstly, increase data rate in wireless channel that uses a fixed amount of spectrum by improving modulation, antenna and MAC protocols to increase bits/sec/Hz. In the second approach, each node could use different frequency to connect different nodes and nodes in same communication area could communicate simultaneously in same time in different frequency [7]. For increasing the network capacity and reducing interference, multi radio interfaces have been utilized in WMNs by assigning different channels to network's access points to support multi transmitting in the neighbouring region simultaneously. In addition it makes advantage of channel diversity for load interference balancing within the access points. Real time monitoring could be used as performance indicator to get lower end-to-end delay [19]. Metric of Interference and Channel *(*MIC), Weighted Cumulative ETT *(*WCETT) and **W**eighted **H**op, spectrum-**A**wareness and s**t**ability *(*WHAT) are some metrics which support multi radio channel in WMNs.

The reminder of the paper is organized as follows, we will consider metrics in four different categories, Traditional one which is Hop-count, and then link quality metrics such as ETX and other metrics are considered in second section. Load-dependant metrics are described in the third section and fourth section considers the multi channel metrics. The last section is conclusion and summery about all metrics.

2. Hop Count

Hop count is the most popular and IETF standard metrics. It is simple to be calculated by devices even the devices which have low resources in CPU, memory or energy such as Wireless Sensors. This metrics avoid any computational burden on devices regarding to find the best route to the destination on most

routing protocols. The path weights equal to the total number of routers through it. This metrics does not bring the packet loss ratio or transmission rate or interference into the account for calculating the cost of links [1][9]. Hop count is more attractive where quality link could not be found in case of mobility [8]. In hop count routing metric inherently quantizes the state of a communication link between two nodes as "up" or "down" state [3].

3. Link-quality metrics

Link-quality metrics look to the quality of each link in the path and the metrics are based on parameters of link quality. Expected Transmission Count or ETX was proposed by De Couto, et al as a metric in 2004 [4]. ETX is calculated based on packet loss rate collected from MAC layer and it is the predicted value of data transmissions that deliver a packet successfully over a wireless link. ETX is a metric that is calculated in each node and for each link. The calculation is based on the probability that the packets are successfully transmitted between sender and receiver in a bidirectional manner. Forward delivery ratio or df is the probability that a packet is received successfully at the receiver end. The probability that a packet is received successfully at the sender end is called reverse delivery ratio or dr. Reverse delivery ratio is calculated based on reception of ACK packets that receiver sends to sender to acknowledge that a packet was successfully received. The probability that a packet is sent to receiver and receivers acknowledgment is received by sender is $df \times dr$. ETX is defined as one over probability of successful transmission as: $\mathrm{ETX} = \frac{1}{\mathrm{df} \times \mathrm{dr}}$.

One of the weaknesses of ETX is the calculation is based on a small packet that may be the link could not perform the same if the packets are significantly large [6]. The other limitation in the ETX is not taking into account the asymmetry of traffic on the wireless links. ETX is designed for single radio with single channel environment and it is not multi radio support [5]. Potential Transmission Count (PTC) has been published as a new metric by Arun Kumar Singh et al in 2011 that it was not a novel metrics as it is the same calculation as ETX that it has been published before.

Moving Average Expected Transmission count (AETX) has been proposed by Fariborz Entezami et al in 2012 to make ETX more stable during the time. They have shown that ETX fluctuates during the time affects routing protocols performance and last three average of ETX makes it more stable and better performance in case of topological variations over the channel [10].

Expected Link Performance (ELP) has been introduced by Usman Ashraf[I]in motivation on improvement on existing ETX. ETX as a link quality metric calculates the metric of links based on packet loss in sending and receiving packets over wireless communication link. ETX as a metric does not measure the asymmetry of traffic on wireless link and also the ETX’s mechanism uses different packet size in sending packet and receiving ACK packet and it gives equal weightage to both sides in calculation. ELP for solving this weak point of ETX define a parameter such as α which give a weight to forward packets against the backward packets [6].

ETXMulti has been published by Andre Riker et al in 2011. Multimedia traffic is contented more than %50 of all communication traffic in 2012 and it will rise up to %80 in 2022 [11]. They have presented a new routing metric based on ETX concept to assure find the best path for multimedia traffics. Real-time multimedia applications do not use (TCP) for their communication and instead they use User Datagram Protocol(UDP) which does not use ACK in its protocol. ETX is based on probability of success transmission on both ways and in UDP protocol only one way is used and ACK does not send to sender [11].

ETX-Embeded has been proposed by Chen Wang et al in 2007 based on combination of network‘s topological structure and channel quality. The geographic routing is an ideal approach for routing protocols to find the best path in end to end solution. In geographic routing, it is assumption that a packet can be moved closer to the destination in the network topology if it is moved geographically closer to destination in physical space [11]. This assumption is correct wherein the wireless network nodes are distributed uniformly and use the wireless channels with perfect transmission status. Some time the geographical routing may lead a packet to a local minimum or low quality route [11]. *ETX*-Embedded tries to improve the end-to-end routing performance by embedding a wireless sensor network into Euclidean space where the virtual distance of each nodes equal to the ETX or probability the number of expected transmission for a packet to be delivered between two pair nodes successfully [11].

Interference and Bandwidth adjusted ETX (IBETX) is a quality link metric that is proposed by Nadeem Javaid et al. in 2010 for wireless multi-hop networks. IBETX is abed on three parameters, first, Expected Link Delivery (ELD) that is based on finding the paths with the least expected number of retransmission, such at ETX. Second, *Expected Link Bandwidth (ELB)* that provides nominal bit rates to find the best path between two nodes among a set of contending links. Third is expected interference of the link that is calculated based on MAC information [8].

Modified ETX (mETX) is published by Can Emre Koksal et al in 2006 [3]. It considers the changes on communication channel during the time period that could take to account directly as parameters. It considers how time-varying channels effect throughput and an optimized routing metrics could improve performance. mETX is combined by two parameters, average and the variance of the error probability respectively [3].

Medium Time Metric (MTM) has been proposed by Baruch Awerbuch et al at 2004. MTM has been designed for utilizing in multiple transmission rates networks. The traditional routing metric such as hop count used in single rate networks. In multi rate networks, long distance links operate in low effectiveness throughput and low reliability based on the low signal level.

Statistical Estimate Routing Metric (SERM) has been published by XU Baoshu and Wang Hui in 2010 and it is an ETX based metric with the aims of working by a limited energy devices and with reliable transmission on wireless sensor network. SERM is figured based on statistics mean of packet reception ratio and correlation coefficient of moment estimator of packet reception ratio [12].

EFW-Selfish behaviour is called to action of wireless nodes in the network to increase their network utilization by ordering to prioritize their own traffic and dropping selected packets sent by neighboured routers. To cope with this problem, Stefano Paris et al propose a novel routing metric in 2011 called EFW. EFW is a metric with combination of Expected Transmission Counter (ETX) and forwarding behaviour. To address selfish behaviour to this metric, the forwarding reliability of a relaying node is added.

Expected Multicast Transmission Time (EMTT) has been published by Xin Zhao et al in 2011 as a high throughput reliable multicast metric in multi-rate wireless mesh network. EMTT takes to account reliability in MAC layer retransmission, transmission rate diversity, advantage of wireless broadcast and link quality awareness [15].

Effective Number of Transmission (ENT) is published by Can Emre Koksal et al in 2006 [3]. It is based on packet loss such as ETX and mETX and also it takes visibility of packet loss for upper layers protocols such as TCP and count on maximum transmission limited in higher layers. It considers the changes on communication channel during the time period that could take to account directly as parameters. It considers how time-varying channels effect throughput and an optimized routing metrics could improve performance [3].

Estimated Transmission Time (EstdTT) has been introduced by Saniel Aguayo etal in 2006. They used this metric for the SrcRR that was a new routing protocol for 802.11 mesh networks. They used an extended version of ETX by predicting the best 802.11 transmission bit rate. The goal of EstdTT was to predict the time that each packet will use the channel and make it busy. The accumulative of EstTT of each link makes the total cost of the route. EstdTT is calculated based on the highest possible throughput and the delivery probability of ACKs in both directions [16].

Draves et al. has proposed Expected Transmission Time (ETT) as a routing metric in 2004 [17]. The motivation of ETT was to improve ETX by bring the parameters of transmission rate and packet size into the calculation. The cost of a link is calculated based on MAC layer duration for a successful transmission. The cost of the path is calculated by summation of the ETTs of the links on the path. ETT such as ETX is isotonic and another drawback in ETT is that it does not calculate the inter-flow and intra-flow interferences [17][9].

Weighted Integrated Metrics (WIM) has been proposed by Bijil Raj M. B et al in 2011 as a dynamic and generic routing metrics which they claim this metric could use in wild range routing protocols for finding reliable path with consistent throughput. They claim that this metric perform well in highly unstable wireless network [18].

4. load-dependant Metrics

Bottleneck Aware Routing Metric (BATD) takes into account intra-flow interference, link loss rates and diverse data transmission rates within a path. In this metric, the total transmission delay time of each independent channel within one path on the links with the same carrier sense rang is measured and the largest amount of the transmission delay time is considered as the bottleneck channel in the path [20].

Distribution Based Expected Transmission Count (DBETX) is a metric that its calculation is based on physical layer measurements and channel information such as noise floor and other local information such as the selected modulation scheme. DBETX has three goals [4], first one is to monitor the variations on wireless channel and second is reflect the maximum MAC layer retransmission limit and third is to select links with lower loss probability[4]. Based on these link measurements, nodes are able to estimate Probability Density Function (PDF) of the experimented Signal-to-Noise plus Interference Ratio (SNIR).

Expected Available Bandwidth (EAB) has proposed in 2010 by Junhung Kim et al to cover the gap of considering links with high communication traffic in previous metrics. EAB claims to provide high throughput and low average end-to-end delay while the traffic is high in the network. This metrics takes to account the available bandwidth and the successful transmission ratio [21].

EDR-[5] they found that transmission interference behaviour is highly dependent upon the wireless link loss rates. They have proposed a transmission interference model based on the IEEE 802.11 medium access control protocol. In this model, the transmission contention degree of each link use as wireless link loss function, impact function of wireless link loss on medium access backoff and concurrent transmission when two links do not make interference to each other [5].

MF-Transmission Failures and Load-Balanced Routing Metric has been published by Imad Ullah et al in 2011 which consider transmission failures by IEEE 802.11 backoff mechanism and also assign weights to each path which are used as path metrics and could use as load balancing parameters to balance traffic across the network to avoid making congestion area. MF takes to account inter-flow interference and intra-flow interference with quality of link with capacity of providing load balancing across the network [13].

5. Multi channel Metrics

iBATD-The original BATD metric is based on total transmission delay time in a multi radio network on the bottleneck channel along the path. Expected transmission delay (ETD) in each channel computes as the total ETT values of links within the same carrier sense range. The ETT value for each individual link is calculated by S/B in which S represents the frame size and the B denote to the data rate. As the S/B does not take to the account the MAC layer overhead along with each packet transmission, the BATD could be improved by iBATD to increase the accuracy by using iETT value instead of ETT value. IBATD is more accurate than BATD to present the performance of the bottleneck links [20].

iAWARE metrics has been presented by Anand Prabhu Subramanian and Scot Miller in 2007 to assist routing protocols for multi radio infrastructure mesh networks which nodes use multiple radio frequency interfaces. By using this metric, the best path has been chosen based on reducing inter-flow and intra-flow interference. This metric aim is to find paths with links with low loss ratio, high data rate and low level interference experience [7].

Interface Delay Aware Routing (IDAR) metric has been proposed by Qiming Tian in 2010 for multi interface WMNs. IDAR takes to account inter-flow and intra-flow interference within two nodes. IDAR integrates packet loss and transmission ratio and transmission delay as a metric to choose the best path. IDAR selects the path with minimum interference and transmission delay to forward packets.

Exclusive Expected Transmission Time (EETT) has been published by Weirong Jiang at al, for supporting large-scale multi-radio mesh networks (LSMRMNs) that traffic could travel much longer than small scale networks. Channel distribution on long paths makes a significant impact on the throughput performance. EETT is an interference aware routing metrics that select multi channel routes with minimizing interference for high end-to-end throughput. It cannot consider the longer paths due to lake of mechanism that could calculate the interferences among whole neighbour's links [14].

Multi Channel Routing (MCR) metric has been published by Pradeep Kyasanur et al in 2005 to cover the gap of routing metrics for supporting multi channel and multi interface networks. They proposed a link layer protocol to manage multiple channels over IEEE 802.11. In multi interface concept, the available interfaces are classified in two different types, Fixed interface denote to interface which works in specific fixed channel and Switchable interface that can be switch between different channel more frequently.MCR selects channel diverse routes based on taking the interface switching cost into the cost link [23].

Metric of Interference and Channel-switching (MIC) has proposed by Yang et al. in 2005 [17] which are based on minimum ETT in the network, the usage of radio's Interface and channel switching cost. The minimum ETT in the network which is represent of minimum transmission rate of wireless interfaces. IRU is Interference-aware resource Usage that is calculated based on ETT multiple by neighbour numbers and CSC is Channel Switching Cost. The interference range is always much larger than the transmission range and this makes MIC unrealistic because transmission on a link could makes interference on another link that is not on its transmission range but it is in its interference range.

Weighted Cumulative ETT (WCETT) is the first routing protocols metric that consider channel diversity in multi channel networks [9]. It uses a tuneable parameter to balance the weights and a number that represent the number of times that channel is used or experienced intra-flow interference in that channel. WCETT gives low cost to the paths that use more diversified channels with less intra-flow interference [17][9]. It can be used in LQSR that is on-demand routing or other distance vector routing [17].

Expected ThroughPut (ETP) has been proposed by Vivek P. Mhatre et al in 2007. ETP as a MAC-aware routing metric takes into the account the bandwidth sharing mechanism of 802.11 DCF and consider that slow links may degrade the throughput of neighbouring fast links. Considering the bandwidth sharing makes ETP more accurate to calculate the throughput estimations than previous metrics [2]. ETP is based on measuring link's expected throughput that captures bandwidth sharing mechanism of 802.11 DCF [2]. ETP can be used for multi-radio and multi channel networks as a metric for routing protocols.

WHAT-**W**eighted **H**op, spectrum-**A**wareness and s**t**ability has been published by Jian Chen et al in 2010 to select high performance end to end path in multi-hop cognitive wireless networks. In a cognitive wireless networks finding a path based on time-varying spectrums and status of primary users is more difficult than traditional networks. WHAT takes into the account the opportunistic spectrum access and path stability by synthesizing channel switching frequency, usage of licensed channels and path's length to evaluate the quality in an end- to-end path. WHAT uses a tuning parameter to weight two parts of its equation, standard deviation of a node along a path and the total usage of the licensed channels used in the next hop node along the path [22].

6. Conclusions

In this work, we studied most of metrics in WMNs and specification of each metrics has been described briefly. The metrics in general has been considered in link quality metrics, traffic aware metrics and in the end, the metrics which consider in multi channel environment has been studied. A comparison table has been provided in appendix that compares these metrics by network parameters such as packet loss ratio or packet switching cost.

References

[1] Javaid, N.; Bibi, A.; Djouani, K.; , "Interference and bandwidth adjusted ETX in wireless multi-hop networks," *GLOBECOM Workshops (GC Wkshps), 2010 IEEE* , vol., no., pp.1638-1643, 6-10 Dec. 2010

[2] Mhatre, V.P.; Lundgren, H.; Diot, C.; , "MAC-aware routing in wireless mesh networks," *Wireless on Demand Network Systems and Services, 2007. WONS '07. Fourth Annual Conference on* , vol., no., pp.46-49, 24-26 Jan. 2007

[3] Koksal, C.E.; Balakrishnan, H.; , "Quality-Aware Routing Metrics for Time-Varying Wireless Mesh Networks," *Selected Areas in Communications, IEEE Journal on* , vol.24, no.11, pp.1984-1994, Nov. 2006

[4] de O. Cunha, D.; Duarte, O.C.M.; Pujolle, G.; , "An Enhanced Routing Metric for Fading Wireless Channels," *Wireless Communications and Networking Conference, 2008. WCNC 2008. IEEE* , vol., no., pp.2723-2728, March 31 2008-April 3 2008

[5] Jun Cheol Park; Kasera, S.K.; , "Expected data rate: an accurate high-throughput path metric for multi-hop wireless routing," *Sensor and Ad Hoc Communications and Networks, 2005. IEEE SECON 2005. 2005 Second Annual IEEE Communications Society Conference on* ,

[6] Ashraf, U.; Abdellatif, S.; Juanole, G.; , "An Interference and Link-Quality Aware Routing Metric for Wireless Mesh Networks," *Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th* , vol., no., pp.1-5, 21-24 Sept. 2008

[7] Subramanian, A.P.; Buddhikot, M.M.; Miller, S.; , "Interference aware routing in multi-radio wireless mesh networks," *Wireless Mesh Networks, 2006. WiMesh 2006. 2nd IEEE Workshop on* , vol., no., pp.55-63, 25-28 Sept. 2006

[8] Javaid, N.; Bibi, A.; Djouani, K.; , "Interference and bandwidth adjusted ETX in wireless multi-hop networks," *GLOBECOM Workshops (GC Wkshps), 2010 IEEE* , vol., no., pp.1638-1643, 6-10 Dec. 2010

[9] Weirong Jiang; Shuping Liu; Yun Zhu; Zhiming Zhang; , "Optimizing Routing Metrics for Large-Scale Multi-Radio Mesh Networks," *Wireless Communications, Networking and Mobile Computing, 2007. WiCom 2007. International Conference on* , vol., no., pp.1550-1553, 21-25 Sept. 2007

[10] Entezami, F.; Ramrekha, T.A.; Politis, C.; , "An enhanced routing metric for ad hoc networks based on real time testbed," *Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 2012 IEEE 17th International Workshop on* , vol., no., pp.173-175, 17-19 Sept. 2012

[11] Riker, A.; Quadros, C.J.F.; Aguiar, E.S.; Abelem, A.J.G.; Cerqueira, E.; , "ETXMULT: A routing metric for multimedia applications in wireless mesh networks," *Communications (LATINCOM), 2011 IEEE Latin-American Conference on* , vol., no., pp.1-6, 24-26 Oct. 2011

[12] Xu Baoshu; Wang Hui; , "A reliability transmission routing metric algorithm for wireless sensor network," *E-Health Networking, Digital Ecosystems and Technologies (EDT), 2010 International Conference on* , vol.1, no., pp.454-457, 17-18 April 2010

[13] Ullah, I.; Sattar, K.; Qamar, Z.U.; Sami, W.; Ali, A.; , "Transmissions failures and load-balanced routing metric for Wireless Mesh Networks," *High Capacity Optical Networks and Enabling Technologies (HONET), 2011* , vol., no., pp.159-163, 19-21 Dec. 2011

[14] Weirong Jiang; Shuping Liu; Yun Zhu; Zhiming Zhang; , "Optimizing Routing Metrics for Large-Scale Multi-Radio Mesh Networks," *Wireless Communications, Networking and Mobile Computing, 2007. WiCom 2007. International Conference on* , vol., no., pp.1550-1553, 21-25 Sept. 2007

[15] Xin Zhao; Jun Guo; Chun Tung Chou; Misra, A.; Jha, S.; , "A high-throughput routing metric for reliable multicast in multi-rate wireless mesh networks," *INFOCOM, 2011 Proceedings IEEE* , vol., no., pp.2042-2050, 10-15 April 2011

[16] Daniel Aguayo; John Bicket; Robert Morris;, "SrcRR: A High Throughput Routing Protocol for 802.11 Mesh Networks (DRAFT)" Technical Report, 2004.

[17] Yaling Yang; Jun Wang; , "Design Guidelines for Routing Metrics in Multihop Wireless Networks," *INFOCOM 2008. The 27th Conference on Computer Communications. IEEE* , vol., no., pp.1615-1623, 13-18 April 2008

[18] Raj, M.B.B.; Gopinath, R.; Khishore, S.; Vaithiyanathan, S.; , "Weighted Integrated Metrics (WIM): A Generic Algorithm for Reliable Routing in Wireless Mesh Networks," *Wireless Communications, Networking and Mobile Computing (WiCOM), 2011 7th International Conference on* , vol., no., pp.1-6, 23-25 Sept. 2011

[19] Qiming Tian; , "A New Interference-Delay Aware Routing Metric for Multi-Interface Wireless Mesh Networks," *Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on* , vol., no., pp.1-5, 23-25 Sept. 2010

[20] Bing Qi; Fangyang Shen; Raza, S.; , "iBATD: A New Routing Metric for Multi-radio Wireless Mesh Networks," *Information Technology: New Generations (ITNG), 2012 Ninth International Conference on* , vol., no., pp.502-507, 16-18 April 2012

[21] Junhyung Kim; JangKyu Yun; Mahnsuk Yoon; Keuchul Cho; Honggil Lee; Kijun Han; , "A routing metric based on Available Bandwidth in wireless mesh networks," *Advanced Communication Technology (ICACT), 2010 The 12th International Conference on* , vol.1, no., pp.844-849, 7-10 Feb. 2010

[22] Jian Chen; Hewu Li; Jianping Wu; , "WHAT: A novel routing metric for multi-hop cognitive wireless networks," *Wireless and Optical Communications Conference (WOCC), 2010 19th Annual* , vol., no., pp.1-6, 14-15 May 2010

[23] Kyasanur, P., Vaidya, N. H., "Routing and Link-layer Protocols for Multi-Channel Multi-Interface Ad Hoc Wireless Networks" Technical Report May 2005