Routing in WOBAN: A Review

Asad Ali

***Abstract*—Hybrid Broadband access networks (WOBAN) are cost-effective and flexible solution to overcome the increasing demand of the access network. The back-End of the WOBAN being optical has very high performance both in terms of speed and bandwidth. This is not the case with the front end in WOBAN. So there has been lot of research and numbers of protocols were designed and numerous algorithms have been proposed to bring the performance of the Front-End at par with that of the optical part and to reduce the delay that occur for data in reaching from End-User to Optical Network Unit (ONU). So in this paper we review the various protocols and algorithms designed to enhance the performance of wireless part of WOBAN, the various approaches that are used to overcome the delay in the wireless part. We than compare all the approaches and algorithms in a tabular form.**

***Index Terms*—WOBAN, access network, ONU**

I. Introduction

There has always been an increased in the demand of the bandwidth. Also there is a tremendous increase in the access network traffic and particularly with the introduction of services like high definition TV, Video Conferencing, telemedicine and other bandwidth hungry applications, the need for such a network that support enormous data and that has high capacity and bandwidth is apparent. Also optical network provides high data rate, low transmission loss, and low bit error rate, Ultra-high bandwidth to meet the growing demand, improved performance, and increased transmission rate. On the other hand, wireless network has also greatly influenced our lives. They provide number of advantages like mobility, flexibility, lesser cost. So Wireless Optical Broadband Access network (WOBAN) was proposed so that there may be a flexible and cost-effective solution to the increased demand of access network. WOBAN is the hybrid of the Wireless and optical networks. It combines the best feature of the wireless and optical networks. Though, the communication scenarios of both are totally different from each other [1]. Optical network are used for high bandwidth and for long-haul communication and wireless to provide flexible connectivity. So in WOBAN we combine both in an efficient and cost-effective manner in order to take the advantages of the best features of both. In this paper we will not only discuss the routing algorithms used for reducing the delay but also we will discuss routing metrics that can be used for efficient routing and on which most of the modern routing algorithms are based. Rest of the paper is organized as follows. Section II shows the Architecture of WOBAN, Section III shows various metrics that can be used for routing at the back end of WOBAN, Section IV shows various routing algorithms. We have shown the performance analysis of various algorithms in Sections V, in Section VI and Section VII we have given our conclusion and future work.

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Asad Ali is with the School of Electrical Engineering and Computer Science, National University of Science and Technology (NUST), Islamabad, Pakistan (e-mail: asad.ali@seecs.edu.pk).

II. Architecture of WOBAN

WOBAN is an optimal combination of an optical back-end and a wireless front-end for an efficient access network [1][2][3]. Architecture of a WOBAN consists of wireless part- The Front-End and the optical part-The Back-End. At the back end, there is a Central office (CO) the Optical Line Terminal (OLT) resides in CO. The CO and the wireless part is connected through a trunk fiber. At the wireless part, first of all there are gateway routers called ONUs. The rest of the wireless nodes are connected to these ONUs. The distance between the ONU and the CO is almost 20Kms. However, this distance can be decreased or increased depending upon the requirement and the number of ONUs to be supported. End-users whether stationary or mobile, are connected to the network through the wireless nodes. There is an optical splitter between the OLT and the ONUs. The optical splitter, being passive device, so overall the architecture is more robust. For communication in downward direction, that is, from CO towards ONU, the packet is broadcast. The optical splitter split the signal equally among the entire ONUs. The entire ONUs rejects the packet except the one for which the packet is aimed. In upward direction, when end users want to send data packets, it does so by passing the packet to the nearby nodes. That nearby node passes the data packet to its other neighboring node nearer to the ONU. In This way, packet pass hop by hop to different nodes to reach the ONU and then from ONU, through splitter, ultimately to the OLT. From OLT, the data packet is sent in the similar fashion discussed above, that is, the packet after reaching the OLT is sent back over the same fiber trunk. The optical splitter splits the signal equally among the ONUs. The entire ONUs will reject the packet except the ONU in which there is the targeted user of the packet. If this packet is meant for a node out side this WOBAN, it is routed by the CO outside the network. So in wireless part when the data packet is passed hop by hop, doing various kinds of processing and making routing decision at each hop. There comes a significant delay. Since the optical part has high capacity, high bandwidth, and thus high speed, so the performance of the wireless part must be brought at par with that of the optical part. So first of all this delay must be reduced, in order to match with the speed of the optical part, up to some extent.

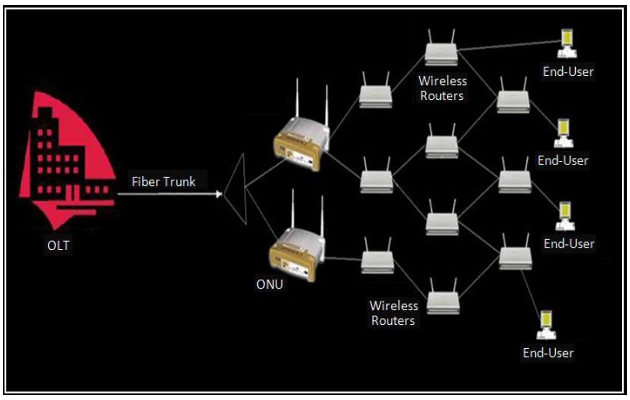

Fig. 1. Architecture of WOBAN.

III. Metrics for Routing

Different researchers use different matrices for computing the best path. Routing metrics are the integral part of the routing protocols designed for wireless mesh networks. These routing metrics are used in the routing protocols to determine the best path to route traffic from source to destination among different available paths. The reference [5] inspects different requirements for the designing of routing metrics that gives high throughput and less traffic delays. These requirements base on the routing protocols and the characteristics of a wireless mesh network. There are different routing metrics already proposed by different researchers few of these are Hop Count, ETX, ETT, WCETT and MIC. So in this section we will briefly discuss them in order to highlight that they can be used in complement with other routing algorithm for efficient routing of data packet in the wireless part of WOBAN. Different routing Metrics were proposed for efficient routing in WMN and every newer one has some improvements over the earlier one.

1) First one is Hop Count that is a simple one technique to route traffic from source to destination. For this approach, the link either exist or not i-e binary concept. It does not provide good performance as it does not considers the transmission rates and packets loss ratio. So the path chosen might not be the path with a good throughput.
2) Expected Transmission Count (ETX) [9] was proposed by De Couto, and is based on the expected number of Transmissions required to successfully deliver a packet at the destination on a particular link. This metric considers the packet loss ratio and the path lengths. ETX is calculated based on the history of the transmission of the packet, that is, the higher the packet loss or path lengths then higher the ETX value, total weight is calculated by summing up all the ETX values along the paths.

To calculate ETX we need 'p' and s (k)

$$p=1-(1-p_f)\times(1-p_r)$$

p is the probability that packet transmission is not successful from x to y; and p_f, p_r are packet loss probabilities in forward and reverse directions on the link.

$$s(k) = p^{k-1}\times(1-p)$$

where $s(k)$ is the number of attempts in which packet is successfully delivered from x to y

Now $ETX = \sum_{k=1}^{\infty} k \times s(k) = \frac{1}{1-p}$ is the expected number of transmissions required to successfully deliver the packet. Drawback of this metric is that it does not consider the interference among channels and also the delay that a packet may suffer. This problem is overcome by [6].

3) Expected Transmission Time (ETT) [6] proposed by Draves based on the expected duration required to successfully deliver packet on the link.

ETT is based on the ETX value. Knowing the value of the ETX, ETT can be calculated as follows;

$$ETT = ETX \times \frac{S}{B}$$

where S is the Size of the packet and B is the bandwidth.

ETT of all the links must be added to get the ETT of the entire path i-e Weighted Cumulative ETT (WCETT).

$$WCETT = \sum_{i=1}^{n} ETT_i$$

The drawback of this metric is that it does not fully capture the interference requirement.

Similarly there are some other Metrics. Metric for Interference and Channel-switching (MIC) gives the best performance in terms of less end-to-end packet delay and high throughput. Another metric proposed in[7] with the name Expected throughput ETP which uses bandwidth sharing mechanism of 802.11 DCF. ETP provides more accurate throughput estimates than other metrics and is suitable in multi-channel networks. Slower links of wireless networks decreases the throughput of neighboring fast links. These situations are not handled by the other metrics such as ETX. Reference [8] proposed a new routing protocol Load-Aware routing metric LARM that provides the load balancing in the WMN .load balancing is a major issue in wireless mesh networks that degrades the overall network performance. When load balancing is not considered in the routing protocols some link may become congested and remain underutilized. Unbalanced load in the network may also cause some gate ways to become congested .to increase network utilization load balancing is also required.

IV. Routing Algorithms

Various Algorithms have been proposed for routing at the front end of WOBAN and are discussed below.

A. *MHRA and SPRA*

Multi-hop routing algorithm (MHRA) and Shortest-path routing algorithm (SPRA) [1], [2], are both traditional approaches to routing. In case of MHRA the link metric is unity, while on the other hand SPRA is inversely proportional to link capacity. Both SPRA and MHRA are based on shortest path, so they do not consider other characteristics of the network like congestion, available bandwidth, load on the link etc. Sometime the shortest path may not be the path on which the data reaches soon. So both

MHRA and SPRA do not overcome the delay problem, load balancing or congestion problem.

B. PTRA

Predictive-throughput routing algorithm (PTRA) [1], [2], unlike SPRA and PHRA is not based on the shortest path. In fact, it selects the path among the number of alternative paths based on the link state advertisement (LSAs) shared among the nodes. PTRA chooses the path with the highest throughput. The path with the highest throughput is only estimated on the basis of the history of LSA. Though PTRA gives good throughput but it does not take in to the account the delay sensitivity of the data packet. Since, it does not take into the account the relative delay for the packet, so the path with the highest throughput might be the longer path and the packet may travel the longer path. Thus there may be significant delay in the delivery of the data packet. The case worsens for the delay-sensitive data. The path with the highest throughput may not be the shortest path. As we are want to choose the shortest path having highest throughput and least delay.

C. DARA

DARA [2] is a proactive routing protocol, tries to minimize the delay, avoids congestion and provides load balancing. It considers wireless routers on a path up to gateway as a queue and LSA's are periodically advertized that tells about the wireless link states. Based on these LSA's, weights are assigned to links, the higher the delay then higher the weight. A user sends a packet to the nearby router, when packet arrives to the router it computes the end to end delay and forwards the packet to the link on the path which has the minimum delay.

There are four types of delay that DARA takes into account in calculating total delay from end to end, namely Propagation delay, Transmission delay, slot synchronization delay and Queuing delay. The total delay calculated on node *i* is

$$W_i = \left(\frac{1}{\mu C_i} + \frac{1}{2\mu C_i} + \frac{\rho_i}{\mu C_i - \lambda_i}\right) \qquad (1)$$

In above equation $\frac{1}{\mu C_i}$ is the transmission delay, $\frac{1}{2\mu C_i}$ is slot synchronization delay and $\frac{\rho_i}{\mu C_i - \lambda_i}$ is the queuing delay where in queuing delay ρ_i is the queuing delay where is queuing delay $\frac{\lambda_i}{\mu C_i}$ Thus, DARA computes the path with the minimum predicted delay from a router to any gateway and vice versa. However, since it mainly relies on the LSAs, so the network condition may change dramatically after a LSA up to another LSA. So in that case the estimation may go wrong. Another prominent shortcoming is that it involves too much processing and decision making, which itself introduces a delay.

D. CaDAR

Abu Reaz et all, have proposed a very good algorithm in order to overcome the delay in [3]. CaDAR not only calculate the least delay path but also assign capacities to the nodes very efficiently due to which the overall throughput of the path increases considerably. In this paper too, the authors have identified 4 types of delay which are same as in DARA. So in CaDAR too, the authors first calculate all the four types of delays for all individual links and then ultimately delay is calculated for the overall path by adding up all the delays for all the links. In this way the total delay from the source to the ONU is calculated. The path with the least delay is selected for forwarding the packet. CaDAR is based on DARA; however it assigns capacities to the link upon receiving LSAs. Thus it support high traffic load very well. But again like DARA it involves too many calculations for choosing the least delay path. Another shortcoming is that it heavily relies on LSAs, so again due to change in network conditions, the estimations may some time go wrong.

E. IADBR

In reference [9], the authors calculate the shortest path to ONUs with the least delay by two methods, IADBR $_{cen}$ and IADBR $_{dis}$. IADBR $_{cen}$ make a list of possible paths in decreasing order and deletes the path with the highest delay one by one until it finds the path having highest delay in the list with the delay less then delay bound. It calculates the shortest path by Dijkstra's Algorithm. Since this method relies on link states flooding which can consume a major chunk of the bandwidth, therefore the author introduces another method, IADBR $_{dis}$. In this method, shortest path is calculated through Bellman Ford's algorithm, each node maintaining the shortest paths to various ONUs. Though, the authors quite effectively find the shortest path with minimum delay. Overall impact on the delay is good; i-e chooses the shortest path with least delay due to which overall delay is reduced. However, , since the technology is moving towards energy saving aspects, so we must also take into the account the time when the traffic on the network is low, thus allowing some of the intermediate nodes and ONUs to go idle, thus saving energy. IADBR does not include those features. Each node needs to maintain the shortest paths to various ONUs. Also, finding the shortest path involves so many RREQ and RREP messages, so it is clearly wastage of energy. We must make the processing as lesser as possible, but it is not the case at all in IADBR.

V. Performance Analysis

Fig. 2 shows that DARA performs much better than MHRA, SPRA and PTRA in terms of average delay.

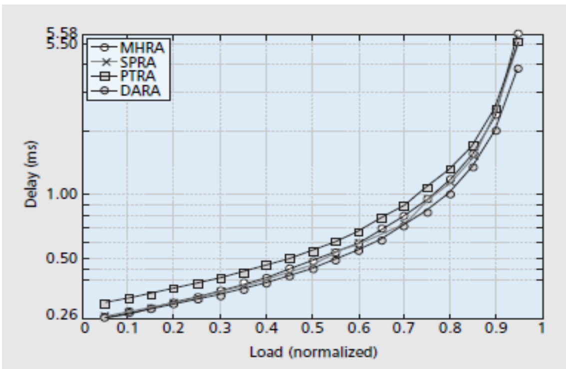

Fig. 2. Average delay Vs load.

Observation shows that at low loads (0.40) MHRA and SPRA performs comparably with DARA. Both MHRA and SPRA works on shortest path techniques, thus at low loads these two algorithms have higher probability to find the shortest path with least delay. At high loads of 0.95 the average delay for DARA nearly 30 % from its competitor PTRA. Fig. 3, compares the individual path delays for the four protocols. After load 0.5 PTRA delay shoots up and over takes SPRA delay, DARA performs well then all other.

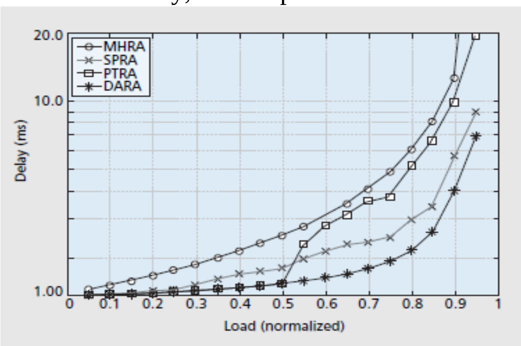

Fig. 3. Delay Vs load for single route.

Fig. 4 shows the average hop counts of all the four protocols. The Fig clearly shows that MHRA, SPRA and DARA produce minimum number of hops. The Fig also shows that DARA performs much better then PTRA at all loads.

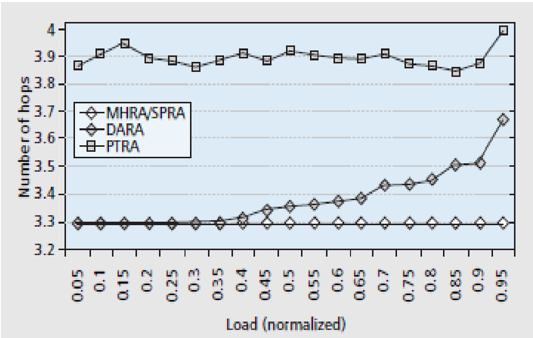

Fig. 4. Hop distribution and load balancing.

Fig. 5, shows how well the algorithms perform in case of congestion in the link and balancing the load. Traffic difference is plotted in this graph (Maximum Packet intensity – Minimum Packet intensity). Smaller this difference betters the load balancing or link congestion. The Fig shows that though MHRA and SPRA find the shortest path but both are failed in balancing the traffic. However, performance of PTRA and DARA is almost equal up to the load 0.75 but later on PTRA performs better, as is expected, since PTRA works on the basis of throughput.

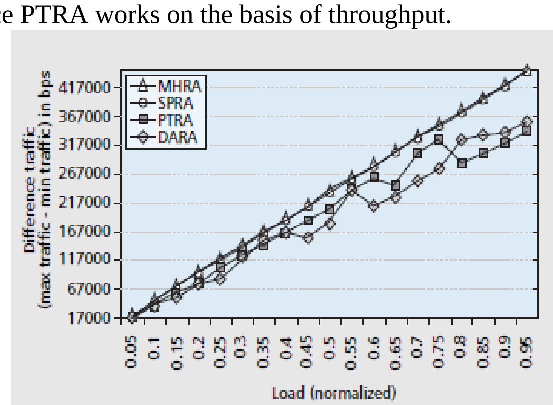

Fig. 5. Load balancing Vs load.

In Fig. 6, DARA and CaDAR are compared. CaDAR performs significantly well then DARA. Fig. 6, shows that CaDAR support three times load then DARA can do while still having much lesser delay than DARA.

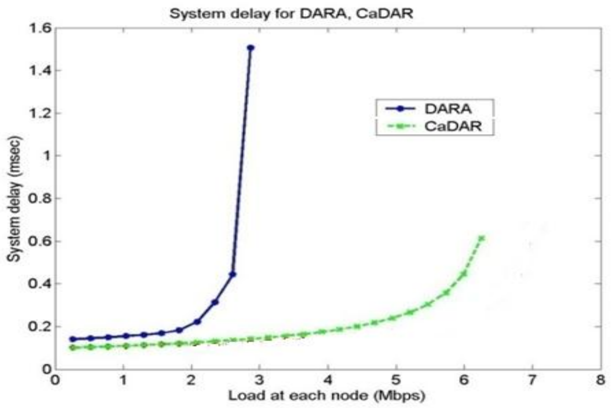

Fig. 6. Load Vs system delay.

Fig. 7 shows that CaDAR has approximately the same average hops as DARA, since both are delay-aware routing algorithms.

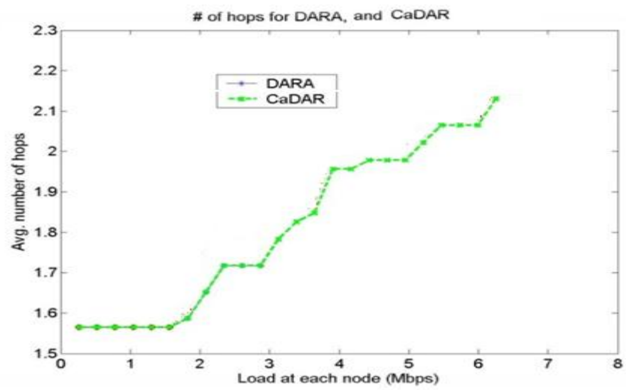

Fig. 7. Loads Vs number of hops.

CaDAR also provides better load balancing than DARA regardless of whatever the load may be. This is shown in Fig. 8.

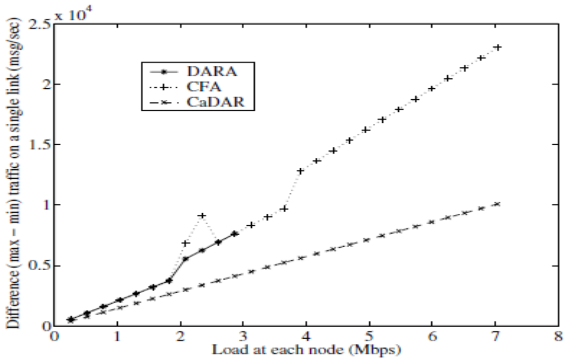

Fig. 8. Load Vs load balancing.

Analysis in Fig. 9 shows the curve for average number paths for IADBR $_{dis}$ and IADBR $_{cen}$. The Fig shows that as number of wireless nodes increases, the hop number of paths also increases. However, IADBR $_{cen}$ performs better then IADBR $_{dis}$, as it selects lesser number of hops in paths then IADBR $_{dis}$.

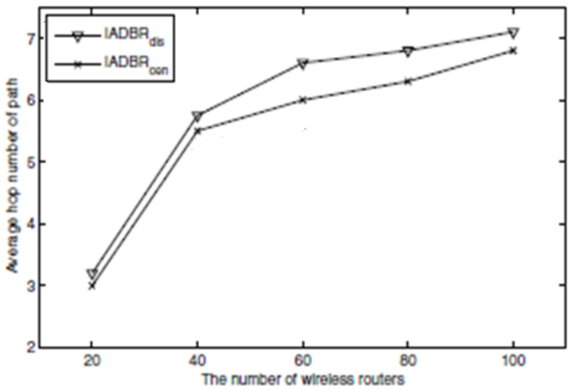

Fig. 9. Number of hops Vs number of wireless routers.

Table I below summarizes the various algorithms discussed above.

TABLE I: COMPARISON OF DIFFERENT PROTOCOLS

Routing Algorithms	Delay Handled?	Good Throughput?	Load Balancing	Relying on LSAs
SPRA	Upto some extent	Not so much	No	Yes
MHRA	Upto some extent	Not so Much	No	Yes
PTRA	No	Yes	Yes	Yes
DARA	Yes but introuduces too much Processing delay	Yes	Yes	Yes
CaDAR	Yes but introuduces too much Processing delay	Yes-throughput higher then DARA	Yes	Yes
IADBR	Yes	Yes	Yes	Yes

VI. CONCLUSION

In this paper we have shown various algorithms for routing in the front-end of WOBAN. First we discuss routing metrics. We discussed the application of these metrics in the wireless part of WOBAN. We then discussed the traditional algorithms and than we moved onto algorithms like CaDAR, DARA and IADBR. We showed that CaDAR is much better then all other approaches. It perform significantly better then all other approaches. In table 1 below we have shown the comparisons of various approaches.

VII. FUTURE WORK

Work can be done on further improving the efficiency of routing algorithm. We can eliminate the processing introduced by these algorithms. In this way not only less time will be consumed but also the energy consumed by the nods will be lesser. We can add a new dimension to WOBAN routing by including energy-saving aspect. Green technology (reducing the carbon footprint) is the new technology buzzword. Apart, we do not need all ONUs to be turned on all the time; same is true for wireless routers as well. For ONUs and wireless routers, we have some redundancies when the load (traffic) is low. As long as we can shut down a few of the ONUs/routers, and can still have connectivity, we can route our traffic. We can also work to assign capacities to the link more efficiently without relying on the LSAs.

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