Power Control for Video Transmission over Rural Wireless Mesh Networks

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Abstract—**Power problems pose a major challenge when deploying wireless mesh networks (WMNs) in rural areas and hinder the sustainability of wireless mesh network in such areas. This paper introduces a mechanism for controlling transmission power for efficient video transmission in power-constrained rural areas. The mechanism increases the operational lifetime of WMNs. It ensures that the little power available to the nodes in such areas is optimally used. Simulation studies were used to quantify the performance gains of this mechanism. Simulation is done by considering a classic and power controlled optimized link state routing protocol (OLSR). We consider an OLSR-based wireless mesh network (WMN).**

Index Terms—Power Control, Wireless Mesh Network, Optimized Link State Routing, Transmission Power, TC, LOS

I. INTRODUCTION

Wireless Mesh Network (WMN) is the current trend in broadband networking that promises to leverage cheap and quick network access to outlying locations such as remote rural areas. It is a self-configurable multi-hop ad hoc wireless network that supports wired devices and it has gateways for providing connectivity to the internet. Wireless mesh networks (WMNs) are capable of extending non-line of sight (NLOS) connectivity to areas without direct line of sight (LOS). It can support a wide range of network services. Wireless mesh routers (WMRs) and wireless mesh clients (WMCs) form the nodes of a WMN [1]. WMRs have little mobility and WMC can be either mobile or static. WMCs can access the network by meshing with other WMCs in the neighbourhood or through connecting to the infrastructure backbone formed by the WMRs.

The type of network access by WMCs depends on the type WMN architecture, for example in client meshing architecture, the WMCs communicate amongst themselves without any infrastructure resembling an ad hoc type of network. In infrastructure architecture, WMCs connect to the network through infrastructure backbone formed by the WMRs. In hybrid architecture, WMC nodes access the network through forming meshing amongst them or through the backbone formed by the WMRs such that hybrid architecture involves both the access modes. Figure 1 shows a typical infrastructure based WMN architecture.

The rapid growth of wireless enabled devices has increased the demand for internet services considerably. This, in turn, has increased the number of mobile internet users. As a result, users continuously demand internet access. WMNs have emerged as a solution for offering wide coverage. WMNs have attracted realtime applications such as transmission of video over the wireless link because of the following benefits [2]:

Are self-configurable
Are self-organized
Involve low up-front cost
Have ease of rollout
Offer reliable service coverage

However, offering these applications in rural areas becomes too difficult because of several challenges. Most rural areas do not have an electricity supply and WMN nodes mostly have to depend on power from sources such as solar batteries and generators. These sources cannot sustain the network lifetime to allow efficient transmission.

A solution is needed for optimizing the available power in the nodes to extend the network lifetime, maximize the network throughput and to reduce delay in the network.

Power optimization in a network is essential because it determines the connectivity of the network ([3], [4] and [5]). It reduces interference and allows spectrum spatial re-use.

A transmission power level that is too high increases the connectivity of the network because of an increase in the number of direct links between the nodes in the network as illustrated in Figure 2(b). However, high transmission power level results in high interference and reduces the network capacity. A very low power level, on the other hand, reduces the number of active links, thereby isolating the network nodes leading to network partitioning, as represented in Figure 2(a). An optimized power level allows for full connectivity of the network with reduced interferences and maximized network capacity as shown in Figure 2(c).

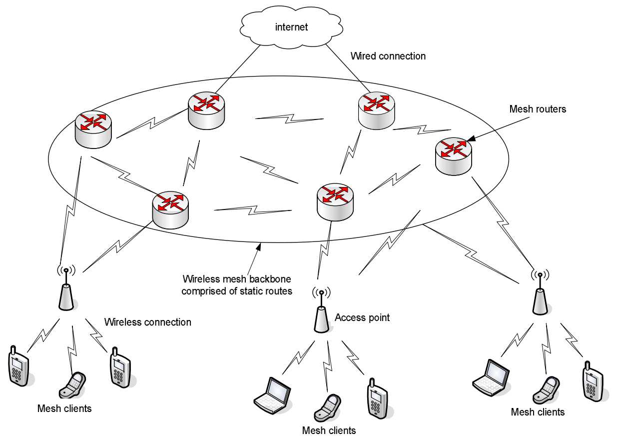
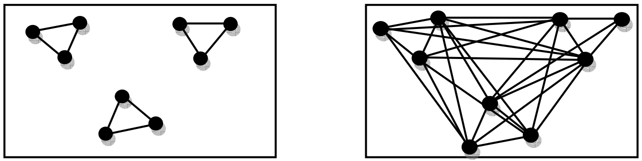


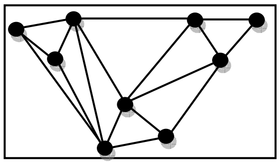
Figure 1: A typical infrastructure based WMN architecture

The need for optimum power transmission in WMNs has initiated extensive research. Each researcher seeks the best power control mechanism. However, many of these research projects are based on ad hoc and sensor networks. Little research has been done and few projects have focused on WMNs.



(a) Low transmission power level

(b)High transmission power level



(c) Optimal transmission power

Figure 2: Figures a, b and c show the impact of power level on network connectivity

In this paper, we present a power control mechanism with the objectives to maximize the network throughput, extend the network lifetime and minimize energy consumption in the network. We implement this mechanism based on optimized link state routing (OLSR) protocol and we also propose some modifications to this protocol. OLSR is used in this case because its distributed nature makes it ideal for WMN. We conduct our simulation tests for the power controlled OLSR and the classic OLSR to evaluate the effectiveness of our mechanism.

The rest of this paper is organized as follows:

Section II - Presentation of related work on power control
Section III - Review of OLSR protocol
Section IV - Detailed description of our power control Mechanism
Section V - Video traffic generation
Section VI - Discussion of simulation results
Section VII - Conclusion

II. RELATED WORK ON POWER CONTROL

The purpose of most research on power control in wireless mesh networks has been to solve problems related to topology control, MAC layer (such as contention) or energy optimization.

Authors in [6] proposed an algorithm that turns off the wireless local area network (WLAN) interfaces when in the idle state and wake them up when there is incoming long lived multimedia data. In [7] and [8], it is observed that many channel coding schemes can lower the transmission energy significantly by transmitting packets over a long time. In [8], it is further observed that, to minimize transmission energy, we can vary transmission times and power levels to get the optimal schedule for transmitting the packet within the given time. In [9], nodes are configured to power themselves off when not participating in an active transmission or reception in the network. In [10], the problem of minimizing the energy used for packet transmission over a wireless link via lazy schedules has been considered. Packet transmission schedules are carefully varied. It is observed that the energy required to transmit a packet can be reduced significantly by lowering transmission power and transmitting the packet over a long time. This may not be suitable for real time applications such as video because they are sensitive to delay.

In [11], a solution is proposed that involves modifying the IEEE 802.11's handshaking procedure to allow nodes to transmit at a low power level. A common power (COMPOW) protocol is proposed in [12] for power control in Ad Hoc networks. COMPOW maximizes the traffic-carrying capacity of the entire network, extends battery life by providing low power routes and reduces the contention at the MAC layer. In [13], an algorithm that improves the power saving mechanism of IEEE 802.11 Distributed Coordination Function (DCF) is proposed. The proposed *New Power Save Mechanism (NPSM)* removes the Ad hoc Traffic Indication Message (ATIM) window from the IEEE 802.11 power save mechanism (PSM) to reduce control overhead that consumes a significant amount of power. In NPSM, nodes awake for a specified duration called DATA window where data transmission takes place.

A protocol known as CLUSTERPOW has been proposed in [14]. CLUSTERPOW is a loop-free protocol for power control, clustering and routing problems. The objective is to maximize the network capacity. It provides a dynamic and adaptive clustering based on the transmit power.

LOADPOW protocol [14] adapts the transmit power to the network load. It minimizes the end-to-end delay by varying the transmit power levels. It involves using high transmit power levels when the network is low and lowering the transmit power when the network load increases. This algorithm eliminates interference by enabling network nodes to avoid using the transmit power that would create interference in the neighbouring communication.

Another approach by [15] minimizes transmission power needed for forwarding packets between the sender and the receiving node in an ad hoc network. Power aware routing optimization (PARO) is presented, where the intermediate nodes (termed “redirectors”*)* forward packets on behalf of different source-destination pairs. This leads to a reduction in the aggregate transmission power that is consumed by wireless devices.

A location aided power aware routing protocol (LAPAR) is proposed in [16]. This protocol makes local routing decisions dynamically so that a near best power efficient end-to-end route is established for packet forwarding. The protocol is fully distributed and only location information of neighboring nodes is exploited in each routing node.

There is no recent proposal for a WMN power control method. A number of methods have been proposed for ad hoc and sensor networks. However, these methods may not be good for heterogeneous networking such as WMNs. The many nodes in WMN can also present a challenge to their implementation. We therefore propose a distributed power control method based on OLSR. Owing to its distributed nature, it can support large numbers of nodes.

III. A REVIEW OF OPTIMIZED LINK STATE ROUTING

Routing protocols can be classified as reactive and proactive [17]. The difference is in the availability of the routes in the routing table. Reactive routing protocols (also termed “on-demand”) determine routes only when they are required. Examples of reactive routing protocols may include: ad hoc on demand distance vector (AODV), temporally ordered routing algorithm (TORA) and dynamic source routing (DSR).

In proactive routing protocols, routes to all destinations are maintained, regardless of whether they are required. Each node maintains tables containing the routing information to all the nodes in the network. Examples of proactive routing protocols include: optimized link state routing protocol (OLSR), destination sequenced distance vector (DSDV), source tree adaptive routing (STAR) and topology based reverse path forwarding (TBRPF).

OLSR is an optimization of typical link state algorithm [18]. It constructs and maintains routing tables by circulating partial link state information to the entire network. This protocol allows hop-by-hop routing whereby nodes use most recent information to route their packets.

OLSR uses the Multipoint Relays (MPR) technique to minimize the possibility of duplicate transmission in the same region [19]. The MPR reduces the number of nodes that broadcasts information on behalf of the other nodes, thereby reducing the overhead of the network. A TC message is generated by an MPR node [18] and it is used to transmit partial link state information. It is regularly sent by every node in the network [20] to declare its MPR selector set. TC messages diffuse information in the network that is used by each node in calculating their routing tables. HELLO packets are sent periodically to gather and transmit up to 2-hops neighbourhood information. HELLO messages are used for link sensing, neighbour detection and for computation of MPR [21].

IV. POWER CONTROL MECHANISM

The mechanism presented in this work is a distributed power control mechanism that is based on OLSR protocol. The protocol is modified to use optimal transmission power level as a link cost function. In a classic OLSR, optimal links are determined based on the hop counts, where the path with the minimum number of hops is considered optimal. However, in this paper we consider the transmission power level of a link as a metric for choosing the best path between the sender and the receiver.

In our design, we considered only wireless mesh backbone comprised of static WMRs. We assumed that there was a LOS transmission between these routers. We also considered OLSR protocol as the routing protocol in the WMN routers. OLSR was selected because it can support both wired and wireless network interfaces, therefore, it can work in both WMRs and WMCs. OLSR allows for customizable protocol expansion and therefore the OLSR message can accommodate optimal transmission power information.

In this mechanism, each packet is associated with the power P_{tx} necessary to transmit it to the next hop. This power is recorded in a packet field. The mechanism requires every mesh router at the backbone to record, in its routing and MPR selector tables, the P_{tx} necessary to transmit a packet from the sender to the next hop node. When a receiver receives a packet, it can use this power and the received power P_{rx} to estimate the path loss of the link between it and the sender. This can be computed as:

$$Path\_Loss = P_{tx} - P_{rx} \tag{1}$$

P_{rx} is the received power. *Path_Loss* includes: multipath fading, shadowing and general path loss. This mechanism allows for the necessary packet transmission power to be determined at every hop. Through this, an optimum power for reaching the next hop node and to the final destination can be estimated. The MAC layer of every node estimates the received power and maintains a table that stores the optimal transmission power to reach other nodes it has communicated with. The receiver estimates the *Path_ Loss* and P_{min} is added to this value to establish the optimal power Ptx_{opt} necessary for transmitting a packet through the link. This can be computed as in equation (2). P_{min} is the minimum power level below which correct packet reception cannot be realized.

$$Ptx_{opt} = Path\_Loss + P_{\min} \tag{2}$$

Ptx_{opt} for every hop is then recorded in the routing table. The network layer uses the established links to determine the optimal path to a destination. Sticking to the tight bound of equation (2) may cause packet loss in cases when the received signal strength falls below P_{min} , we therefore introduce a cushion P_{thresh} to Ptx_{opt} as in equation (3) so as to avoid such unnecessary packet loss and to keep the received signal strength above the P_{min}.

$$Ptx_{opt} = Path\_Loss + P_{\min} + P_{thresh} \tag{3}$$

Broadcast messages, HELLO and TC are sent at maximum power (Ptx_{max}) in the optimized OLSR protocol, since they have no predetermined destination node. We modify these messages to include transmitted power so that HELLO messages will include the power necessary to reach all one-hop neighbours associated with the sending node. On the other hand, TC messages include the power necessary for the MPRs to reach the originator of the message. Any node receiving these broadcast messages has to fix the cost of the link to the transmission power Ptx_{max} so that

$$\hat{P}tx_{opt} = Ptx_{\max} - P_{rx} + P_{\min} + P_{thresh} \tag{4}$$

$\hat{P}tx_{opt}$ is the transmit power for successive transmission by the receiver. This value is introduced in the next HELLO packet as the cost function of a link. For every received video data packet, the receiving node updates the established link in its routing table.

Using periodic HELLO packets, each node in the network can discover its one-hop neighbours. In our mechanism, HELLO packets also contain power to reach these one-hop neighbours. At the same time, each node discovers its MPR selector set by using TC packets. The TC packets are modified to include the power level necessary for the MPR to reach the node that sent the packet. In addition, HELLO messages contain the source address and the list of addresses of the neighbour nodes. When a node receives a HELLO message, it attaches the cost of the link to the power $\hat{P}tx_{opt}$.

For every video packet that is received, the receiving node updates the look-up table to include the cost of established links. The $Ptx_{\max}$ will be updated and replaced with the transmission power of the received video packet. In the case of a TC message, the receiver marks the sender as the next hop node to reach all other nodes in the TC packet list. The receiver then appends the power $\hat{P}tx_{opt}$ that is necessary to transmit the MPRs to reach the node that sent the packet. Below is an algorithmic representation of the power control mechanism:

Algorithm for power control

Sender:

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  Step 1: Couple $P_{tx}$ in pkt field
  Step 2: Send pkt
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Receiver:

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  Step 1: Receive pkt from source node
  Step 2a: Extract $P_{tx}$ from received pkt
  Step 2b: If (sender is NOT already in the list of nodes for
           which $P_{tx}$ is known) {
  Step 2c: Add sender to the list and record $P_{tx}$
             If (sender is on the list of nodes for which the
               initial transmit power is known)
  Step 2d: then use the power of sender in step 2e }
  Step 2e: Calculate the optimal transmit power using
           formula
             $Ptx_{opt} = Path\_Loss + P_{\min} + P_{thresh}$
  Step 2f: Refresh the routing table with the new optimal
         transmit power in 2e.
           Exit
```

V. VIDEO TRAFFIC GENERATION

We use raw video sequence called Foreman which is a YUV QCIF format with 176x144 pixels. This is then encoded using an MPEG-4 encoder to generate an encoded video stream. The type of MPEG-4 encoder used in this case is *ffmpeg* [22]. The encoded video stream is read by the video sender to generate a trace file that is then passed to the simulated ns-2 environment. The trace evaluation can be done using Evalvid evaluation tool [23]. The figure below illustrates the video traffic file generation architecture;

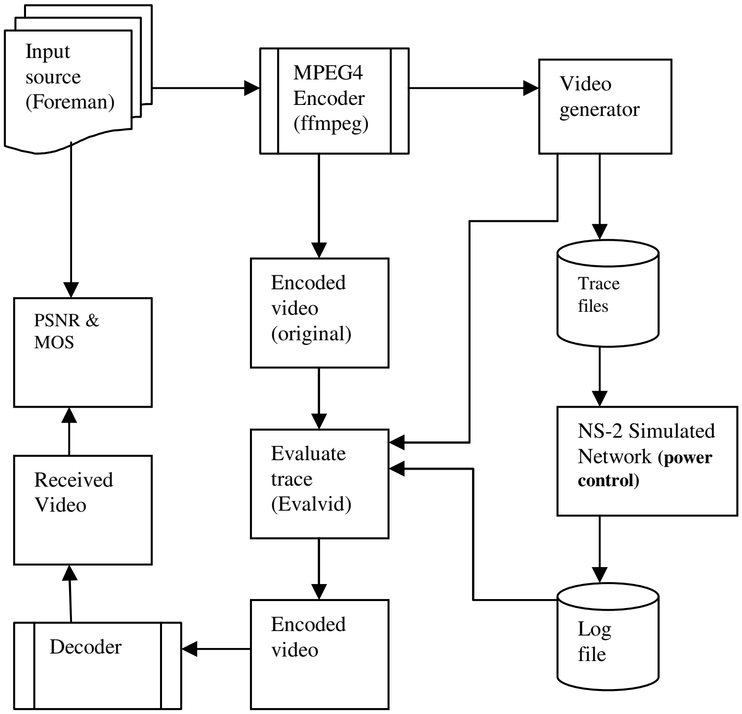

Figure 3: Video traffic generation Architecture

VI. SIMULATION AND RESULTS

We performed some simulation using an ns-2 simulator. Our simulation setup includes simulation time of 500 seconds and a grid topology consisting of static nodes randomly distributed in an area of (1200x1200)m^2 depicting a small area in a rural area covered by WMN. At the network layer, we use Optimized Link State Routing protocol where we test for both classic and power controlled OLSR. At the MAC layer, we use IEEE 802.11b. The propagation model used in our simulation involved both the free space propagation model for short distances less than 100m and two-ray ground reflection model for long distances greater than 100m. Free space was preferred for long distances because it gives accurate prediction of received power. Each node in our simulation is fitted with omnidirectional antennas placed at a height of 1.5m above every node. The simulation is first run without the modifications so that we find the performance of the classic OLSR. We then obtain results for OLSR with the modifications. These are then evaluated using various metrics. Some of the results are presented below:

i) Packet loss as a function of traffic load:

From Figure 4, we can deduce that the percentage packet loss with classic OLSR increases as the traffic load in the network increases. An increase with the power controlled OLSR is also realized, but this is slightly lower than that of the classic OLSR. This implies that the power control mechanism has significantly reduced the packet loss rate

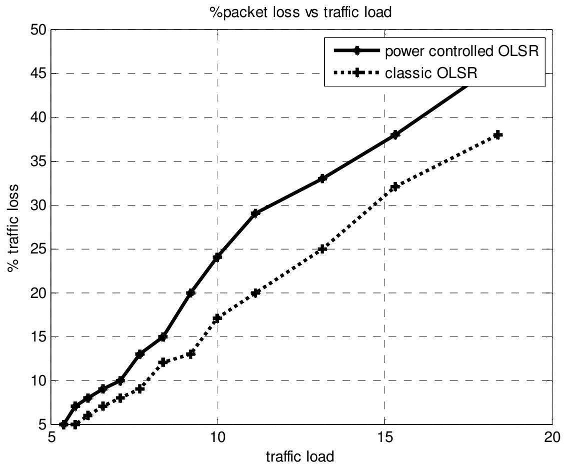

Figure 4: A comparison of packet loss against traffic load

The loss in classic OLSR is due to limited power for the nodes in the network and the little power available is engaged in transmitting packets as well as performing routing functions.

ii) Average throughput

In Figure 5 we evaluate the performance by analyzing the saturated throughput in the network. We take the average throughput for random networks. From the simulation results we realize that average throughput increases significantly with increase in number of nodes in the network. The results also show that power controlled OLSR performs much better than the classic OLSR.

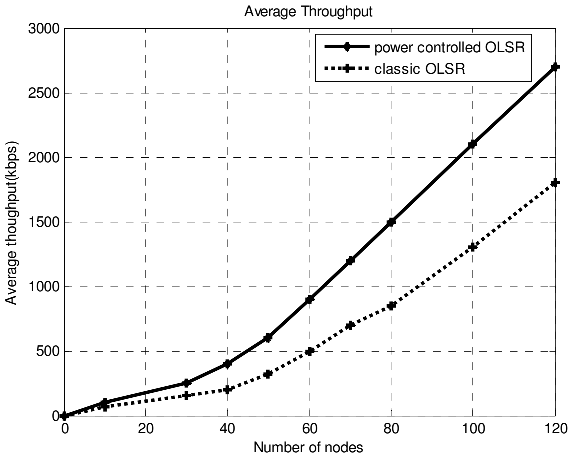

Figure 5: Average throughput

iii) Average remaining energy

This metric gives the total amount of energy remaining at a given simulation time. As shown in figure 6, considering a simulation time of 100 seconds, the power control scheme through the modified OLSR protocol can conserve on average 45% more energy than the classic OLSR.

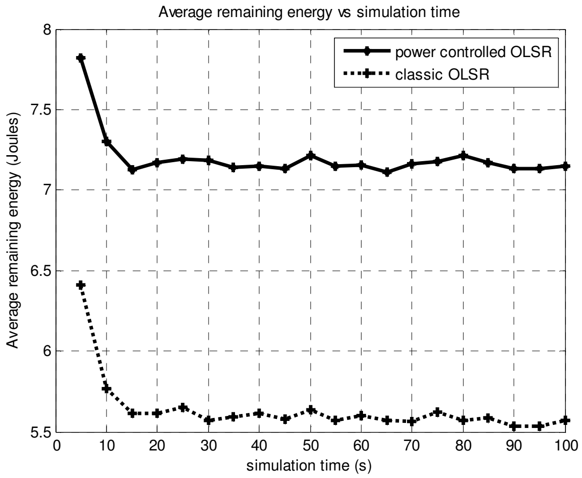

Figure 6: Average remaining energy as a function of simulation time

iv) Network Lifetime

In figure 7 we consider the lifetime of each of the instances. We simulated a network of 60 nodes with random connections. From the figure we can show that the network lifetime is extended more with the power controlled OLSR compared to the classic one. The power controlled OLSR extend the network lifetime to about 700 seconds while classic OLSR extend it to about 300 seconds.

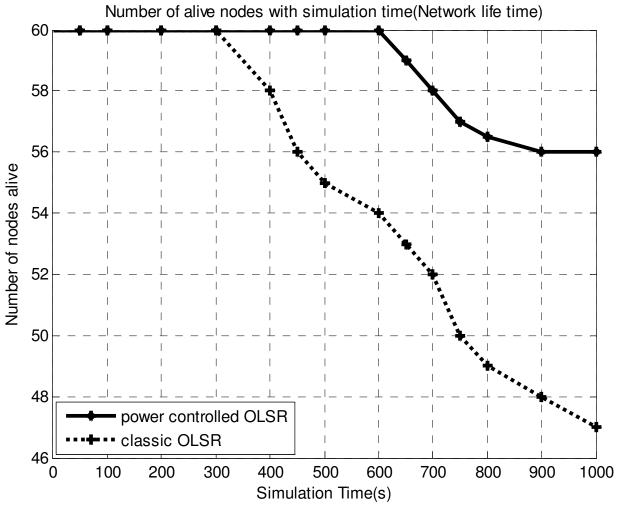

Figure 7: Number of nodes alive against simulation time

VII. CONCLUSION

We have presented a mechanism for power control and optimization in OLSR that maximizes the network throughput and ultimately extends the network lifetime by conserving the power available for the nodes. Simulation results presented showed that the percentage packet loss by power controlled OLSR is lower compared to that of classic OLSR, implying that an improvement on network throughput can be realized. The results also illustrated that, over time, the power controlled OLSR conserves more energy than the classic OLSR.

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