ISSN: 2167-1508
v8 n3675

An Optimized Intelligent Home Network Model

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Abstract

The ever increasing number of devices, services on offer and technological evolutions taking place in the universe has put a lot of pressure on networks. This in turn has affected home networks, which are experiencing low performance due to poor Quality of Service. Therefore, in this paper, we present an optimized home network model that is scalable and adaptable to the various technological changes. The developed optimization model has been simulated, tested and evaluated using OMNET++, with network's packet throughput of 98.41%, loss of 1.59% and delay of 3.02 seconds being experienced, resulting into an available, reliable and optimized performing network throughout.

Keywords: Intelligent networks, weighing factor, VLAN, performance, optimization, QoS.

1. INTRODUCTION

Computer networks existence has spanned over three decades worldwide. Environments such as offices, campuses, military bases, government institutions etc. have their electronic devices connected to aid in communication and sharing. Home environments have too created a niche as an area that equally requires networking of its devices for sharing, communication and accessibility purposes; this enhances control, scheduling and monitoring of the home and its devices either locally or remotely.

Intelligent home networks have Smart Grid, Bluetooth, Wireless Fidelity (Wi-Fi), ZigBee, Ultra Wide Band (UWB) and Body Area sub networks (Zhang et al., 2011). Each sub network has devices connected to the Sub Network Gateway (SNG), which are further connected to the Home Network Gateway (HNG).

Home devices, as well as the supported application services, continue to grow in numbers; this growth is highly attributed to various technological evolutions taking place in the manufacturing, telecommunication and networking industries which have further resulted into poor performing networks, by affecting Quality of Service (QoS). Present and future home networks are therefore, seen to experience low throughput, unavailable bandwidth, high packet delays and loss etc. that lead to an unreliable, unavailable and poor performing home network throughout.

Through systematic literature review, various factors affecting home networks QoS and the existing optimization models have been identified. Further, an optimization model has been developed; the model classifies and prioritizes the various Classes of Services (CoS) that can be supported by each of the network's devices. Moreover, number of maximum packets transmitted per each CoS per iteration has been increased, in which CoS 6, which has the highest priority, is scheduled to transmit 7 packets, CoS 5 transmits 6 and CoS 4, 3, 2 and 1 transmits 5, 4, 3 and 2 packets respectively. This has yielded high network packet throughput of 98.41%, packet loss and delay of 1.59% and 3.02 seconds respectively as per the OMNET++ simulation, testing and evaluation results. This has further provided an available, reliable and an optimized performing home network both locally and remotely irrespective of increase in devices, services and technological evolutions within the network.

The rest of this paper is organized as follows: In Section 2, we provide a discussion on related work. In Section 3, we present system design and architecture. Section 4 outlines the implementation, with Section 5 presenting results and discussion. In Section 6, we conclude the paper.

2. RELATED WORK

An intelligent home network is able to provide users' automated services both locally and remotely, thus enabling control, automation, comfort, safety, energy conservation and healthcare within homes (Raisul, Reaz & Ali, 2012). An intelligent home network features include digital gates and doors, indoor/outdoor lighting, appliances control, health monitoring devices control etc.

Bhatti et al. (2010), presented a home network QoS harmonization scheme with class based communication protocol. The scheme enabled differentiation of priorities in both 3rd and 2nd layers. Differentiated Service Code Points (DSCP) was used to change the signal state, priority level and protocol ID of the classified and marked packets in layer 3 from standard to harmonize; with the protocols IDs from the mapping table being used by the layer 2 in recovering DSCP values. This enhanced bandwidth allocation within the network. Our scheme uses DSCP too in classification and prioritization of services; however, we have used and increased the packets being transmitted per each CoS as opposed to their approach. This is expected to ensure an available, reliable and an optimized performance of the home network irrespective of increase in number of devices, services and technological evolutions.

Takabatake, presented a simple classifier algorithm for QoS control in home networks. The scheme classified packets into Real Time (RT) and Non Real Time (NRT), and clients into ordinary and high priority. The RT packets, which were the first in priority in the media, were transmitted to high priority clients, therefore, resulting into least delay and maximum throughput; whereas, NRT packets, which had the last priority within the media, were assigned and transmitted to respective ordinary clients, therefore, resulting into high packet delays, loss and least minimum throughput. However, our scheme has identified and prioritized six CoS, increased the number of transmitted packets per each CoS as opposed to the approach. This has enabled maximum packet throughput, minimum packet loss and delay in each CoS, thus ensuring an available, reliable and optimized performance of intelligent home network irrespective of increases in number of devices, services and technological changes.

Wang & Xu (2013), presented a smart home M2M architecture scheme that deployed cloud computing. The scheme used Internet of Things (IoT) in its infrastructure to gather, store and upload processed information into the cloud for analysis and processing. The stored information in the cloud, helped in processing and controlling of the network's events and resources, resulting into real time interactions and bandwidth saves. In our scheme, we have classified and prioritized subnetworks which ensure availability of network's bandwidth; moreover, increase in number of transmitted packets in each CoS ensures an available, reliable and optimized performance of the intelligent home network irrespective of increase in number of devices, services and technological evolutions.

3. SYSTEM DESIGN AND ARCHITECTURE

Fig. 1 shows the intelligent home network system architecture. The Multi-Layer 3 switch is configured as the HNG since it is able to handle large amounts of traffic, supports hardware based packet switching, allows inter VLAN routing and prioritization, prioritizes packets by the 6 bits in IP DSCP and able to implement QoS DiffServe; the Access Gateways and Wireless Routers are configured as SNGs in the network.

The secure server hosts databases, files, mails, configurations, management and security features. The secure router aids in connectivity to remote locations.

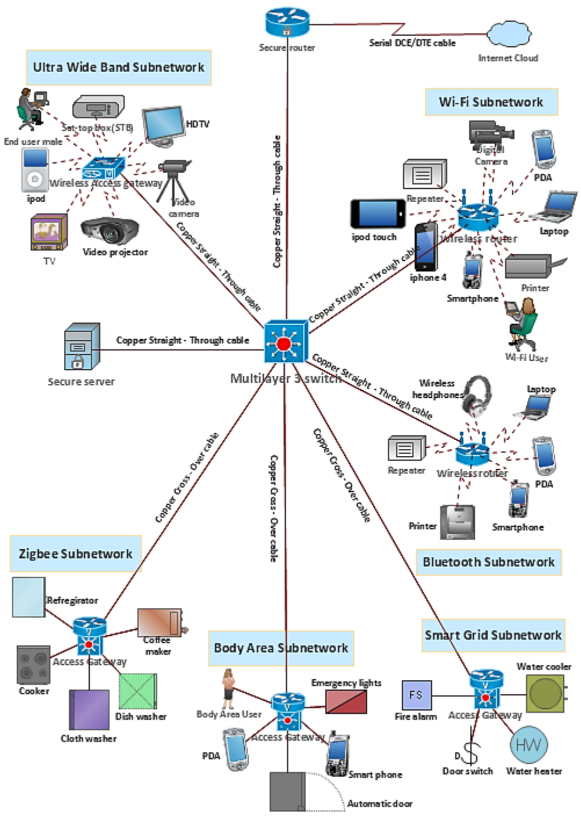

Figure 1: Intelligent home network system architecture.

Most of the network's configurations are done at the HNG. Seven VLANs, 10, 20, 30, 40, 50, 60 and 100 are configured for the SNGs and management. Each VLAN, mostly wired connections, have DHCP pool configured to aid in dynamic allocation of IP addresses to the sub network's connected devices.

Routing protocol, either static or dynamic, is configured at the HNG and the Secure Router to allow intercommunication and communication to the public networks. The wireless routers are configured with names (SSID) and enabled to use Wi-Fi Protected Access (WPA) 2 Personal as the security mode.

The secure router (core network layer) and HNG (network distribution layer) allows for QoS implementation. The access switches (Access layer) with the end devices represent the end point of the network design. The developed algorithm has been implemented at the distribution layer, HNG.

Any incoming remote signal is received at the HNG via the secure router before being disseminated to the relevant SNG and to the intended device within the network, and vice versa for outgoing signal. Local signals begin at the HNG.

4. IMPLEMENTATION

Using Fig. 1, sub networks are identified and prioritized:

$$i_n \in i \text{ and } n = 1,2,3,4,5,6 \text{ and } \quad (1)$$
$$i_6 > i_5 > i_4 > i_3 > i_2 > i_1$$
$$\min_{i \in 6} i_n \text{ and } \max_{i \in 6} i_n$$

Devices are identified and prioritized in each sub network from equation (1):

$$j_n \in j \text{and } n = 1,2,3,\ldots,\infty \text{ and}$$
$$j_n > j_{n-1} > j_{n-2} > \cdots > j_1 \text{ and } j_n \in i_n \quad (2)$$
$$\min_{j \in \infty} j_n \text{ and } \max_{j \in \infty} j_n$$

Based on both equations (1) and (2), the total network's bandwidth is computed by:

$$i_6 j_n b_n + i_5 j_n b_n + i_4 j_n b_n + \cdots + i_1 j_n b_n = \sum_{i,j=1}^{n} b_n j_n \quad (3)$$

Where b_n represents device's bandwidth.

Using equation (2), different CoSs are identified and prioritized for each device:

$$k_n \in k \text{and } n = 1,2,3,4,5,6 \text{ and}$$
$$k_6 > k_5 > k_4 > k_3 > k_2 > k_1 \quad (4)$$
$$\min_{k \in 6} k_n \text{ and } \max_{k \in 6} k_n$$

From equation (4), packets in each CoS are arranged in a linked list as shown in equation (5) where for each iteration:

k_6 transmits a maximum $p_n, p_{n-1}, \ldots, p_{n-6}$ (seven packets), k_5 transmits a maximum $p_n, p_{n-1}, \ldots, p_{n-5}$ (six packets), ... , k_1 transmits a maximum p_n, p_{n-1} (two packets). (5)

Using equation (5), total throughput for each of the CoS k_n:

$$throughput = \sum_{t_p}^{t_{p+1}} packetsize \quad (6)$$

where t_p is the start time of the first packet p; and t_{p+1} is the start time of the next packet $p+1$ after p. Packet size ranges between $0 \le p \le n$.

Using equation (5), the network packet delay is arrived by:

$$Delay = \left\{ \frac{\sum_{t_p}^{t_{p+1}} Delivery\ time - \sum_{t_p}^{t_{p+1}} Arrival\ time}{\sum_{t_p}^{t_{p+1}} Received\ packets} \right\}$$

where:-Arrival and delivery times show the arrival of packets at the MAC layer of the source node and delivery of packets to the MAC layer of destination node respectively; Received packets is total number of packets received between start time t_p of packet p and the start time t_{p+1} of the next packet $p+1$. Total network delay becomes:

$$i_1 j_n d_n + i_2 j_n d_n + i_3 j_n d_n + \cdots + i_6 j_n d_n = \sum_{i,j=1}^{n} d_n j_n \quad (7)$$

Where d_n represents device's delay.

The network jitter is computed by:

$$j = \sqrt{\frac{1}{n-1} \sum_{n=1}^{n} (di - D)^2}$$

Where j represents jitter; di represents the delay per each flow and D represents the average delay for all the flows; n represents the total number of flows.

Packet loss is arrived by:

$$packet\ loss = \left\{ \frac{\sum_{t_p}^{t_{p+1}} dropPacket}{\sum_{t_p}^{t_{p+1}} sendPacket} \right\} * 100$$

In which drop and send packet size $0 \le p \le n$ (8)

Equations (5) - (8) are performed for the remaining devices $j_{n-1} - j_1$ in the subnet. (9)

Equations (4) - (9) are implemented for the remaining sub networks i_5 to i_1. (10)

Simulation
The simulation of the developed model has been performed in OMNET++ as shown in Fig. 2. Both simple modules, representing both the sinks and the source nodes, and network module, which has grouped the nodes using connections, have been used. Duplex communications between the source and sinks and network delay of 100ms have been used in the entire network.

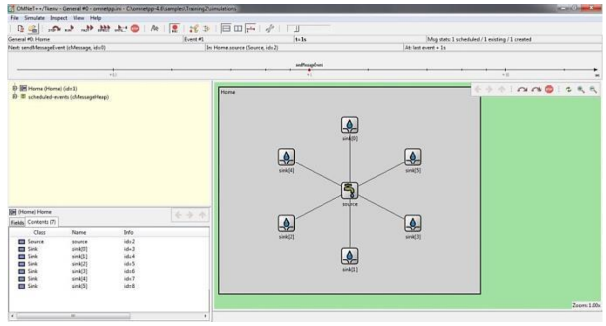

Figure 2: Classes of Services

The sinks [0] – [5] represent CoS 1 – 6 respectively. A total of 27 packets, which is the maximum number of packets that can be transmitted per iteration from the source to the CoS, have been scheduled during the simulation. The above model has generated packet throughput, loss and delay results as shown in section 5.

5. RESULTS AND DISCUSSION

In order to evaluate the performance of the optimized model, the obtained results are presented and discussed in this section.

Simulations have been conducted for Priority Queuing/Strict Priority Queuing (PQ/SPQ), Class Based Weighted Fair Queuing (CBWFQ) and the New Algorithm models to ascertain the objectives of the study.

Network Packet Throughput
Maximum packet throughput is realized in the entire CoS in the three models. The New Algorithm model shows an incremental rise in packet throughput from CoS 1 to CoS 6 as shown in Fig. 3. The packet throughput for the New Algorithm is incremental from CoS 1 that transmits 2 packets to CoS 6 that transmits 7 packets as shown in Fig. 3. Basing on the packet loss results, the network throughput becomes 98.41%, showing an efficient, reliable, available and optimized performing intelligent home network.

Both PQ and CBWFQ transmit uniform number of packets per CoS as shown in Fig. 3.

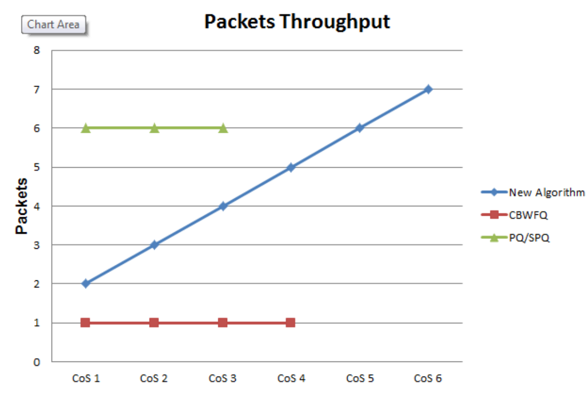

Figure 3: Packet Throughput

PQ transmits 6 packets for each CoS, resulting into 98.92% throughput in consideration to the packet losses results; CBWFQ transmits 1 packet for each CoS resulting into 99.20% throughput in consideration to the losses results shown in Fig. 4. The throughput variation is due to the increase in number of CoS and transmitted packets per CoS in New Algorithm as compared to CBWFQ and PQ that respectively transmit a single packet per CoS iteration and transmission of all the packets in successive CoS.

Network Packet Loss

The New Algorithm has higher packets loss of 0.50% at CoS 1, which is the least prioritized, than in CoS 6, with a loss of 0.14% and the highest prioritized CoS as shown in Fig. 4. This difference represents the need and importance given to each class of service within the network.

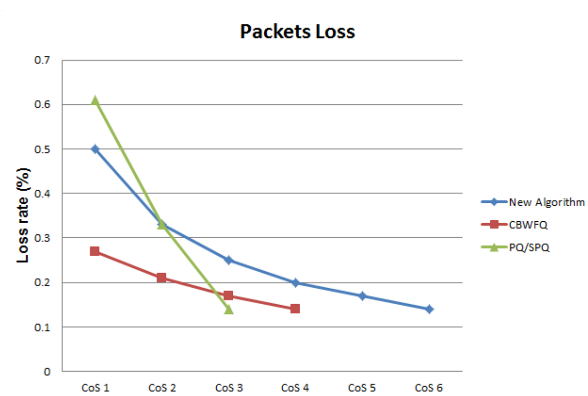

Figure 4: Packet Loss

The loss is further attributed to congestion, queuing, bit errors, different hardware platforms, duration of usage and the configuration and technological standards of the network. The New Algorithm has network packet loss of 1.59%.

Both CBWFQ and PQ have losses of 0.80% and 1.08% respectively. A sharp loss rate is shown in PQ than CBWFQ as shown in Fig. 4. This is due to high serialization and queuing time that packets take in PQ before being transmitted especially for the least prioritized CoS as compared to CBWFQ. However, the New Algorithm shows a steady reduction rate in packets loss despite the increase in number of CoS and packets scheduled for transmission per iteration in each CoS.

Network Packet Delay

The network delay has been measured in seconds (s), in which for the New Algorithm, highest delay of 0.71s has been realized at CoS 1, with CoS 6 having the least delay of 0.37s as shown in Fig. 5. The New Algorithm has a total delay of 3.02s which is attributed to packet queuing, propagation and transmission delays.

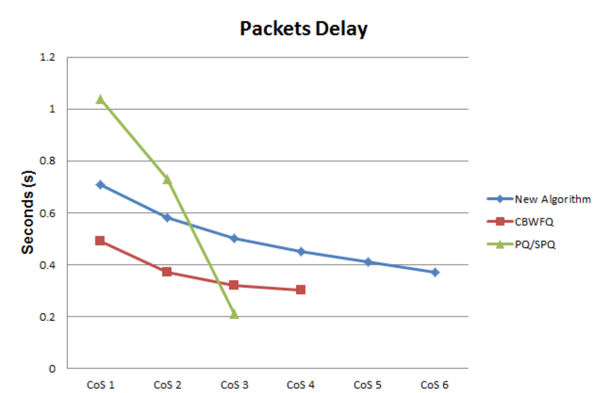

Figure 5: Packet Delay

Both CBWFQ and PQ show larger delays between the CoS than the New Algorithm as shown in Fig 5. This difference is due to the high number of CoS, number of packets on transmission per CoS in the New Algorithm and high transmission, propagation and queuing delays in both CBWFQ and PQ.

6. CONCLUSIONS

In this paper, performance optimization model for intelligent home networks has been described. The classification and prioritization of different SNGs, devices and CoS as well as the increase in number of transmitted packets per CoS for each iteration, has produced simulation output result of network packet throughput of

98.41%, loss of 1.59% and delay of 3.02s. This has yielded a reliable, available and optimized performing home network irrespective of increase in number of devices, services and technological evolutions. The evaluation against the existing QoS models, PQ and CBWFQ, has shown the adaptability of the New Algorithm into the existing or new network infrastructure in leveraging the various technological changes and increases in number of both services and devices, thus making the network to perform efficiently and optimally.

7. ACKNOWLEDGEMENTS

The authors would like to thank Tshwane University of Technology for the technical support.

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