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Network Optimization Using Real Time Polling Service With and Without Relay Station in WiMAX Networks

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Abstract:
IEEE 802.16 can be seen as a compelling replacement for conventional broadband technologies because its primary goal is to provide Broadband Wireless Access (BWA). The variable and uncertain nature of wireless networks makes it much more challenging to ensure QoS in this network. WiMAX Technology is used to support various quality of services which includes UGS, rtps, nrtps, ertps, and Best Effort. This study employs an IEEE 802.16 network simulator, which offers adaptable and reliable features for assessing a particular QoS parameters for rtps. Achieving better internet performance in real time services is currently a challenge, and it is in need of a present scenario. This work emphasized better internet service, with good quality of service using rtps with Relay Station and Without Relay Station. In this work the CBR packet size, CBR data rate, and data rate with rtps service are fine-tuned for achieving better performance with good quality of service. When comparing uplink connections in rtps with and without relay station, it is found that the throughput in the uplink is 200% greater when using a relay station. The throughput and goodput are evaluated in uploading and downloading with single and multiple subscriber stations and we observed that the multiple subscriber stations in downloading give better performance, as compared to single subscriber stations. The throughput and goodput in single subscriber stations is better than multiple subscriber stations in uploading. The academic researchers and commercial developers can use this analysis to validate different WiMAX Network implementation mechanisms and parameters.

Keywords: *WiMAX, real time polling service, QoS, relay station, without relay station*

1. Introduction

In order to offer effective transmission services, a Worldwide Interoperability for Microwave Access (WiMAX) [1] network makes use of the same medium as other networks. Examples of wireless networks that can share wireless files include point-to-multipoint (PMP) and mesh topologies. In a point-to-multipoint mode ground station, many users' stations are connected via a downlink connection. Subscriber stations (SSs) receive the same transmission, or a portion of it, over a particular frequency channel and within the base station's (BS) area of reception.

The only transmitter that operates in this way is the BS. As a result, it broadcasts without requiring any station coordination. Information transmission takes place over the downlink. SSs split the transmission to the BS based on demand. Different services are provided to the subscriber station from the base station based on different quality of services and the requests arriving at base stations. Services such as broadcast, unicast, or multicast are handled by base stations in the form of messages and sometimes are directed to specific subscriber stations too. For every sector, the media access control layer and its associated algorithms governs each subscriber station. This layer is also responsible for handling other functionalities such as delay, bandwidth, and other related applications. Various other types of services, such as unsolicited bandwidth grants, polling and bandwidth sharing, and uplink sharing are also handled by these layers. All this is handled in connection-oriented services in which response is also important. The MAC layer uses a connection-oriented transmission algorithm. In the framework of a connection, all data communications are defined. Service flows are created at subscriber stations, each having a different service flow; a different bandwidth is also associated with each connection. Different quality of service uses different packet data on each type of connection. MAC protocol is based on the idea of different types of service flows and type of connections. Whenever bandwidth is allocated, each type of service flow has a different method for data transfer for both uplink and downlink connections of QoS. Each time a connection is established, an SS seeks uplink bandwidth. According to each connection, an SS seeks uplink bandwidth. Whenever any request arrives at a base station, then on the basis of request a bandwidth is allocated to each subscriber station. All the active connections are kept up until they are not satisfied from the base station. Generally, three types of connections are used in WiMAX networks, which include static configurations including dynamic addition of nodes, modification of connections, and deletion of connections in the network. The base station and subscriber station commonly trigger connection ends between each other.

Real-time service channels, like MPEG video, that periodically produce variable-size data packets are supported by the real time polling service (RTPS).

Services like real time, unicast, and recurring, which satisfies the flow on the basis of services, are also granted on the basis of request and as per the desired size. The attempt is always to provide the best data transport service with efficiency along with the variable grant sizes, but this may require more request overhead than UGS. For effective communications in the network, the base station periodically offers unicast request for data transfer. And for proper operations between the ground station and user station, no contention request is offered from the user station for the link on those services. In case the request is not fulfilled, a unicast request is provided by the BS for the request opportunities as required by this service. To acquire transmission in uplink opportunities as a result, the user station only uses unicast request opportunities. The policy for request and transmission policy should be in accordance with network policy because it has no bearing on how this scheduling service actually works. The main issues which need to be effectively handled by any network include highest sustainable rate of traffic, predefined rate of traffic, maximum latency, and transmission policy requests.

2. Related Work

IEEE 802.16 is the latest technology using the latest hardware and structures, which is applicable for upcoming technologies too. This technology is supported by various tools such as Qualnet, Simulink, and Network simulators. In order to evaluate IEEE 802.16 standards using the NS-2 simulator, this paper provides de-facto standards for the WEIRT project. In order to carry out some special issues that are crucial for conducting trustworthy research based on these tools in realistic scenarios, this article provides some general issues based on research based on this tool. This study demonstrates that hardware frequently only partly complies with standards. It employs NS2 simulations to display real-world situations. A project called WEIRD, which supports NS-2 IEEE 802.16, can also benefit from such study. This essay discusses the concerns necessary to conduct trustworthy NS2 tool-based research [2].

The depicted work in this paper is based on flexible bandwidth allocation and Quality of Services (QoS) schemes of IEEE 802.16 MAC layer for clients with different requirements. In real scenarios QoS is dependent on users in which they can create or modify, updated as per the needs. This paper gives an uplink scheduler, which is used by RTPS in WiMAX networks. A leaky bucket is proposed in this work, in which RTPS connections for scheduling uses the technique for traffic management and for uplink connection management too. Simulation of this work is done on the MATLAB tool in which throughput and fairness are identified. In this study, an uplink schedule for WiMAX base stations' connections to real-time polling services is proposed. For flexible bandwidth distribution, IEEE 802.16 MAC presents the majority of these.

In order to handle uplink traffic, it is suggested in this paper that the ground station keep a leaky bucket for each RTPS connection. The suggested scenario was created using MATLAB and addressed issues with throughput and fairness [3].

Four classifications of traffic in QoS are provided by IEEE in WiMAX networks by the standards. Each class has their own bandwidth requirements, which need to be managed by quality of service (QoS) standards. This work is done by using three types of connections, including UGS (unsolicited grant service), NRTPS (non real time polling service) and RTPS for calculating performance. On the basis of class of quality of services, different levels of priority are assigned. After that an analysis mode is proposed which gives admission control for each type of quality of services. The article suggests and keeps a leaky bucket for each RTPS connection to manage uplink traffic and schedule RTPS traffic. In MATLAB simulations, the suggested scheduler is examined, and its throughput and fairness characteristics are shown [4].

Increasing mobile application has grown up with broadband wireless access (BWA) which enhances mobility and need for data services at all times in mobile applications. Best services for mobile data use new standards of IEEE 802.16e which are available for quality experiences for users. Since WiMAX networks enable a number of characteristics of wireless LANs, so a medium access control layer on the basis of these characteristics ensures video, data, and voice services by the MAC layer. Allocating resources to customers in a way that satisfies all quality requirements like delay, jitter, and throughput is a crucial service. Most of the techniques defined by IEEE are left free so that users can implement them on their own. One important aspect is scheduling, which is needed to implement differentiations. This work is given to designing those factors needed for scheduling. This document provides an overview of current channel-based scheduling methods. In order to improve output while using less energy, this article presents an algorithm with a feasible level of complexity and scalability. The work examines the central concerns and determinants of schedule design. This article provides a thorough overview of contemporary scheduling methodologies. Recent studies are used as the foundation for an extreme survey that classifies the suggested mechanism according to channel conditions. This paper outlines the best use of resources to guarantee service quality and greater throughput while consuming less power and maintaining manageable algorithm complexity and system scalability [5].

This work is discussed about the QoS deployment over cellular WiMAX network. On the basis of deliveries, two quality of service UGS and ERTPS are discussed in this paper in terms of delivery. This paper looks at instances of traffic rising beyond a nominal rate or fluctuating more than beyond nominal rate; we look at the possibility of reverting the free bandwidth out of reserve [6].

This work provides a novel downlink scheduling scheme that takes into account the throughput requirements for delays, fairness optimizations with regard to NRTPS, and best effort to meet the ideal QoS requirement without using excessive amounts of resources. The goal of this work is to accomplish the best QoS requirement without consuming excessive amounts of resources by proposing a downlink scheduling scheme that takes into account the delay requirements of RTPS connections relative to the various NRTPS and BE connections [7].

The WiMAX OFDM downlink subframe uses a two-dimensional channel time structure, which results in additional control overheads and decreased network efficiency. The efficiency of the network is increased by conducting numerous tests to determine the design issues of MAC layer scheduler or the burst allocation in the physical layer. A PUSC model is supported in this work, which identifies cross layer framework using a scheduler and a burst allocator. The data traffic issue is resolved by resource allocation by burst allocator; also, the scheduler can effectively utilize the frame area and cut down on IE overheads. Maintaining long-term fairness, reducing current traffic delays, and improving frame utilization all improve network speed [8].

Quality of Experience (QoE) is used as a base metric in this work, which suggests ways to enhance the capacity of uploading traffic in satellite communication and WiMAX networks in the scheduling algorithm. The FC-MDI (Frame Classification-Media Delivery Index) is used in the scheduling algorithm for real-time connection. The algorithm is assessed in two different iterations. The result shows the performance of the WiMAX network, which increases the delay and quality of experience in real-time connections [9].

Quality of service in WiMAX networks is an important consideration for various applications supported by wireless communications. All the services used for wireless broadband networks can present a challenge, so that services of video, audio voice, and data could be enhanced and improved. An important challenge of wireless services is its unpredictable and variable requirements, which makes it complex to apply in nature. During the transmission of video and voice services, allocation of available QoS criteria like delay, throughput, and jitter are used to maximize the goodput and minimize power consumption with suitable algorithms so as to give scalable and feasible services. WiMAX networks propose quality of service guarantees by using various mechanisms at MAC layer, including scheduling and admission. This also includes packet scheduling in resolving contention for bandwidth among users and to do transmission in an ordered manner. For effective transmission various classifications in terms of scheduling algorithms are proposed, including homogenous algorithms, hybrid algorithms, as well as opportunistic scheduling algorithms. This paper gives performance metrics for developing the scheduler for WiMAX networks.

This paper also gives the improvements associated with uplink scheduling. Numerous scheduling algorithm classifications, including homogenous algorithms, hybrid algorithms, and opportunistic scheduling algorithms, are suggested for transmission in an efficient way. This paper provides efficiency metrics for creating the WiMAX network schedule. This article also discusses the advantages of uplink scheduling [10].

Relaying in WiMAX networks, an emerging topic in recent years that also covers mobile multi-hop relaying, is covered in this work. At first, it was only considered theoretically, but now that it is practically feasible, significant research is being done in this field. This article discusses the scheduling challenge faced by multi-hop relay networks used in OFDM. For user-specific services that require the allocation of bandwidth at a specific moment on a specific channel, scheduling in such systems is a significant issue. According to fairness requirements, the author of this paper suggested the “Eliminate repeat” algorithm to address relay issues in WiMAX network’s current systems. By suggesting a “Service Prioritized Opportunistic Scheduling Algorithm,” the issue is resolved.by allocating bandwidth based on the differentiating bandwidth needed by the user, which decreases the delay and problems of starvation in the networks [11].

The job here is primarily concerned with installation costs that are on a tight budget and network performance issues. Users require more coverage in order to ensure effective radio enhancements and data rates. Relay stations are used in WiMAX networks for network optimization in mobile multi-hop networks. The IEEE 802.16 forum provides various service flows (such as UGS, RTPS, ERTPS, NRTPS, and BE) for various uses. The replacing of the base station from the relay stations at the best possible locations became cost effective and enhanced the coverage. This work depicts aspects of the network quality and coverage enhancements for rural and hilly areas where configuring many base stations is still an issue [12].

The effort provides better support for data, video, and sound services. This study aims to satisfy network design for quality of service [13].

A multipath channel model is proposed in this work, which includes bandwidth over the star trajectory. Four cell scenarios are considered in this work in WiMAX networks. In this proposed work, every cell has one subscriber station and one base station. VoIP codec performance is evaluated in terms of throughput and MOS in this work. The whole work is analyzed in OPNET-14.5. A better outcome is observed using the multipath channel model (disabled) than when using the ITU pedestrian model proposed in this work. This analysis shows that MOS value for the multipath channel model with disable type is superior for ITU Pedestrian Type [14].

The topology and bandwidth of a network affect its performance, and the majority of researchers work to reach high performance in the most efficient manner possible. This article gives a better scheduling algorithm for channel reuse and network performance based on the design and transmission requests in subscriber stations' uplink connection requests.

This paper gives improvements for throughput by reducing transmission delays in mesh network topology [15, 16].

Voice service standards of IEEE 802.16e-2005 are specifically designed for extended real time polling services. For better and optimized results in terms of adaptive modulation, and to maximize transmissions, this adaptive and coding method gives variable rates in according to users' time varying channel conditions. This study gives the idea of cell division in two zones with distinct average SNRs, each with single transmission modes. This paper proposed a 3-dimensional Markov process of M/G/1 to maximize pair of admissible VOIP users for steady state probability and probability distributions [17].

In this study, QoS is deployed in WiMAX networks for wireless cellular networks. The performance achieved with different QoS configurations for VoIP traffic delivery, such as UGS or ertPS, are compared in this paper. The conclusion of this paper demonstrates that the transmission of BE traffic is started if delay-sensitive traffic fluctuates beyond its usual rate from its ERTPS reserved bandwidth [18].

This work compared the performance evaluation of different technologies like Wi-Fi, WiMAX, and UMTS. Testing is done based on modulation and channel bandwidth techniques. Performance of network congestion is identified using network simulation tools to evaluate the results. The obtained results, based on different data rates, vertical handover, and different technologies, offer different services for bandwidth allocations [19].

The following article introduces a novel uplink algorithm called Instantaneously Replacing Algorithm (IRA), which makes use of the NS-2 simulation model. The results of this work represent that the quality of service is increased due to the delay reduction and network resources fairly used by subscriber stations to maintain the throughput using SNR based approaches [20].

Wireless networks' limited resources and time-varying channel circumstances present difficulties for real-time video streaming. Wireless channel circumstances that change over time cause video packets to be lost or delayed under current circumstances. Streaming is encoded and delivered depending on how long it will be played back. Losing base layer packets, particularly in error-prone networks like wireless networks, can have a significant impact on the transmitted video quality and occasionally cause an interruption. This paper is based on behavior of real time published subscriber-based middleware.

The performance of the proposed method is shown in IEEE 802.11g WLAN networks. This paper gives a demonstration of good video quality by stream and stable video free from obvious errors or interruptions [21].

This work proposes a case study of WiMAX network interconnections that are supported on MPLS core. Also, the advantages and benefits in terms of traffic, virtual private networks and Diffserv technologies are studied. Whole analysis is done using a network Opnet simulator with MPLS, MPLS-TP, and GMPLS technologies based on their comparisons with validation on the same infrastructure [22].

In this work various parameters of WiMAX networks are mentioned, which include latency variations based on application runtime, library performances and packet delivery. A network latency injector is designed and proposed in this work, which is suitable for the majority of QLogic and Mellanox InfiniBand cards. The results show that the performance is highly affected with network updating, changes in network variance, and mean network latency [23].

The cloud-based, micro-services-based architecture of today's contemporary business applications requires a flexible, high-performance network infrastructure. Operators' dependency on cloud service platforms is increasing: for instance, the OpenShift Container Platform on Z to guarantee highly available and high-performance applications. For these types of technologies, Open v-Switch (OVS) technologies are used. An important challenge in networking is to have a system with best quality services; many enhancements are still possible in upcoming technologies too. In-depth analyses of the OVS pipeline's effects and a few specific OVS procedures are provided in this paper. The performance of various OVS configuration systems in the industry is used to identify various situations. This study demonstrated how well the OVS pipeline performed, how it operated, and what impact it had [24].

The existing solution beside the WiMAX are 4G and 5G LTE (Long Term Evolution) which used the concept of user capacity increment and signal strength enhancement to increase the coverage area by installing the user capacity site and single strength increment site.

3. Network Structure

The network configuration used in this work to evaluate the effectiveness of the WiMAX relay station is depicted in Figure 1. The network setup consists of one base station, two relay stations, and subscriber stations. The data transmission is made directly from base stations to subscriber station using direct TCP connection, and the other is made through relay stations for uploading and vice versa for downloading. A scenario is constructed using NS2 and the performance is examined with uplink and downlink data transfer from base station to subscriber station and vice versa along with various parameters [25].

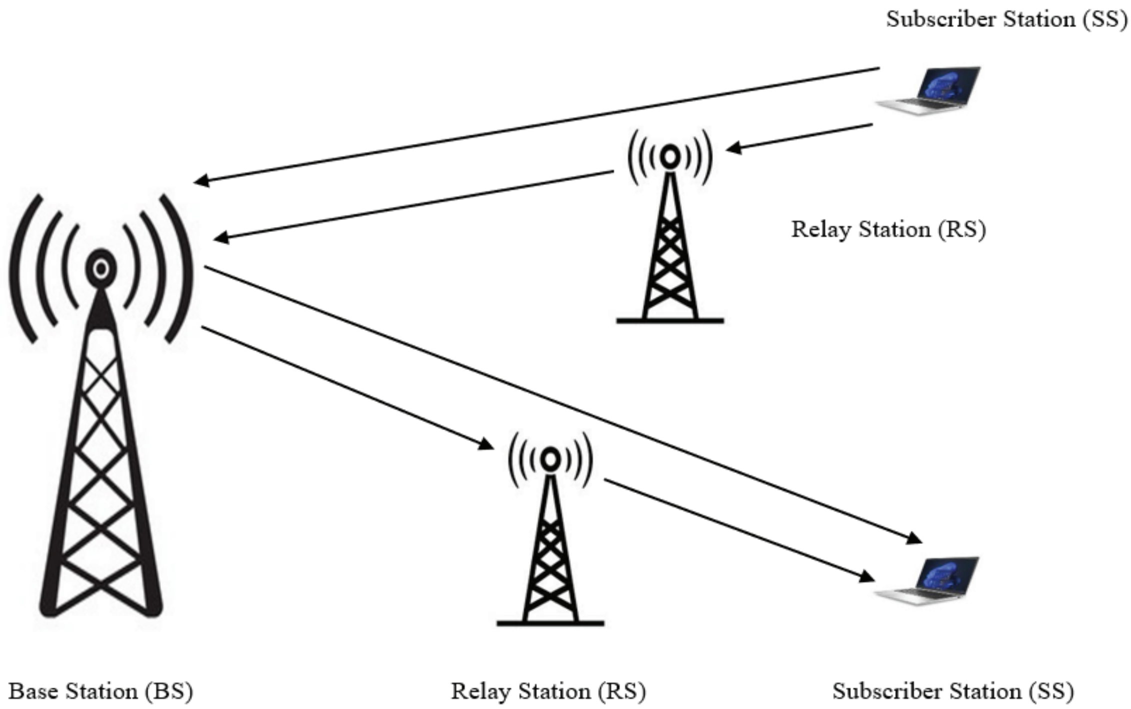

Figure 1. A scenario of RTPS service including base station and relay stations

A base station uses TCP connections to send data to subscriber stations for downlink transmissions and uplink data transfers containing the acknowledgment. In this study, base station to subscriber station downlink TCP connections with and without relay are created, as shown in Figure 1.

In this work the performance is analyzed for uploading and downloading of data from subscriber station to base station and base station to subscriber station respectively using direct TCP connection and via relay station TCP connection.

In this scenario the single and multiple subscriber stations are considered in uploading and downloading both for throughput and goodput measurement.

4. Simulation Parameters

Performance is analyzed using light WiMAX simulator in which two cases are considered. Performance parameters are shown in Table 1.

Table 1. Simulation parameters

Parameters	Values
Routing Protocols	AODV
Transmission Control Protocol	UDP, TCP
Simulation Period	300 Seconds
CBR Packet Size	200 Bytes
CBR Rate	5000000 Milli Sec
Data Rate	1, 2, 3, 10 Sec
Simulation Time	300 Sec
QoS	RTPS

Routing protocol identified the shortest path between source and destination. In this work the base station and subscriber stations are the sender and the receiver. It also functions as a network switch and employs self-defined protocols for interstation communication. The routing algorithm used in this study is called Ad-hoc On Demand Distance Vector Routing (AODV), which is used to create routes only when they are requested. Topology has two different kinds of situations. The scenario used in this case allows packet data transfer between source and destination, which is responsible for end-to-end delivery. Following are the defined values used for simulation study.

CBR Packet size: Inter-arrival packet size

CBR Rate: Constant bit rate is a term describing the behavior of a TCP traffic generator.

Data Rate: The time duration in seconds the data is transmitted

Simulation duration: The duration of data transmission.

QoS: It includes real time polling services which includes audio, video and multimedia services.

5. Performance Metrics

The three metrics are used to estimate the performance of network.

- Throughput: The raw bytes sent between the sender and the receiver

$$Throughput = \frac{Number\ of\ Sent\ Packets * 8}{300} * 10^{-6} \quad (1)$$

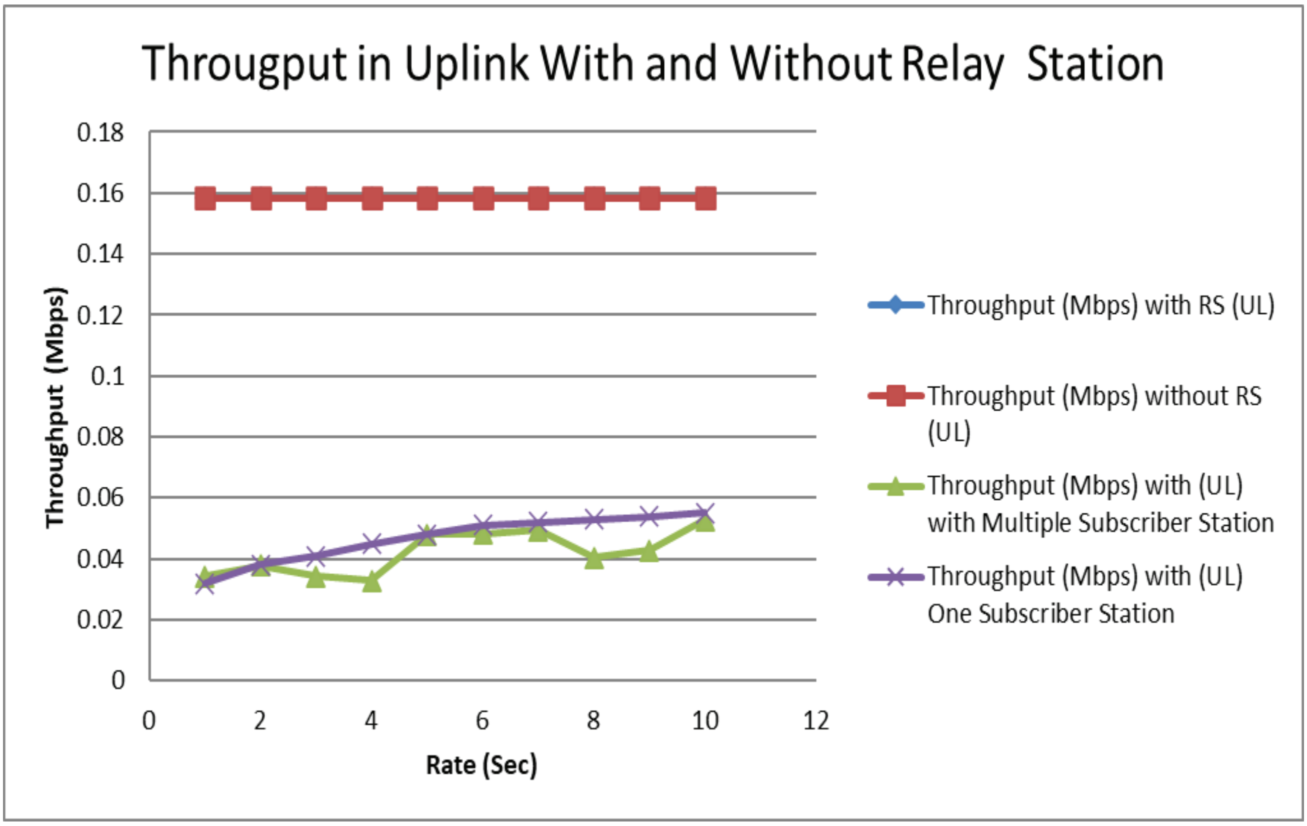

Figure 2. Throughput in uplink with and without relay station in RTPS

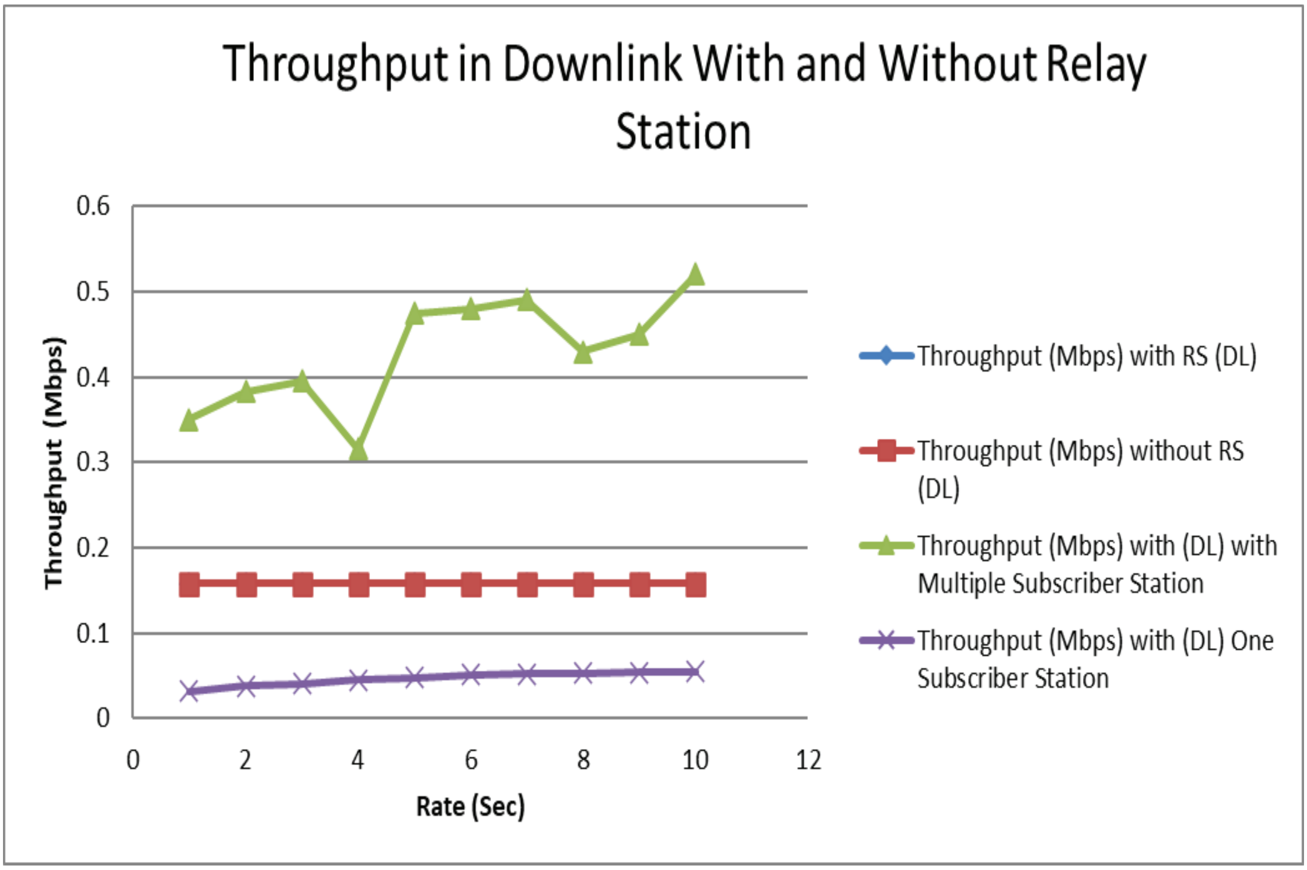

Figure 3. Throughput in downlink with and without relay station in RTPS

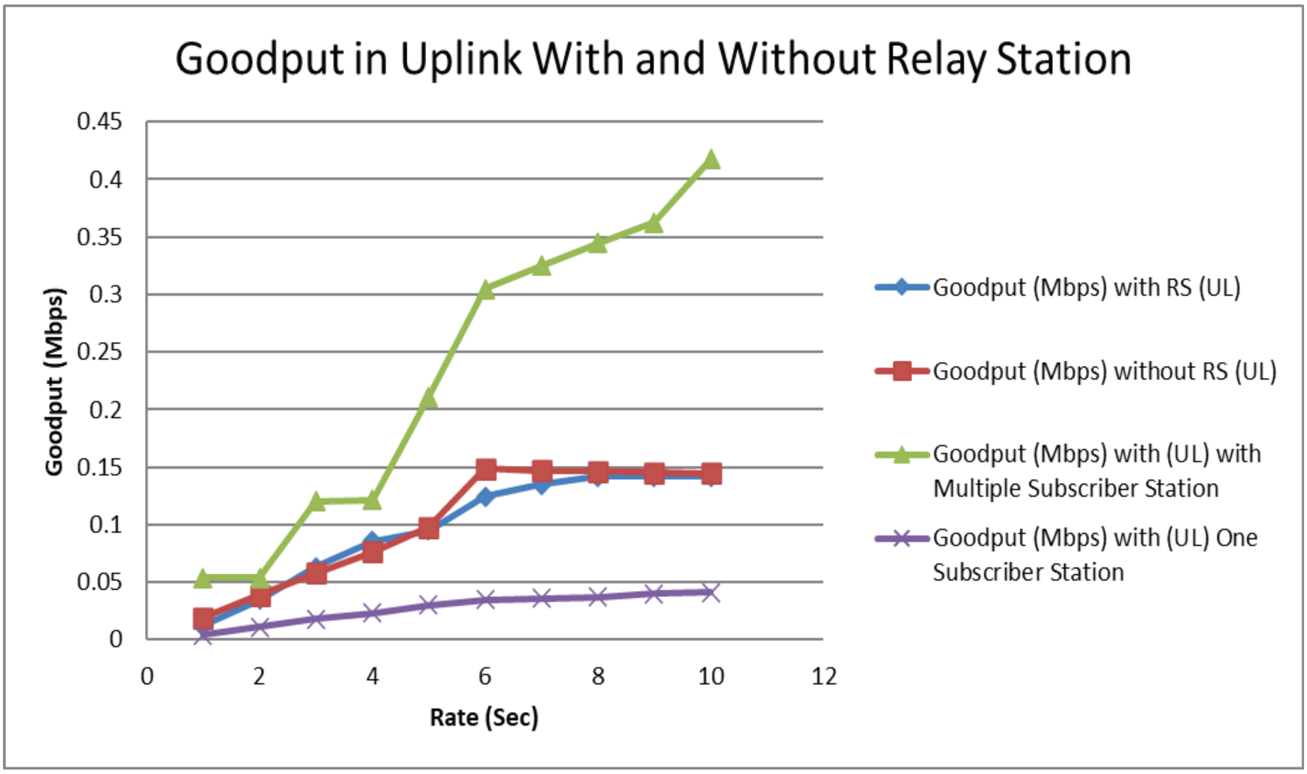

Figure 4. Goodput in uplink with and without relay station in RTPS

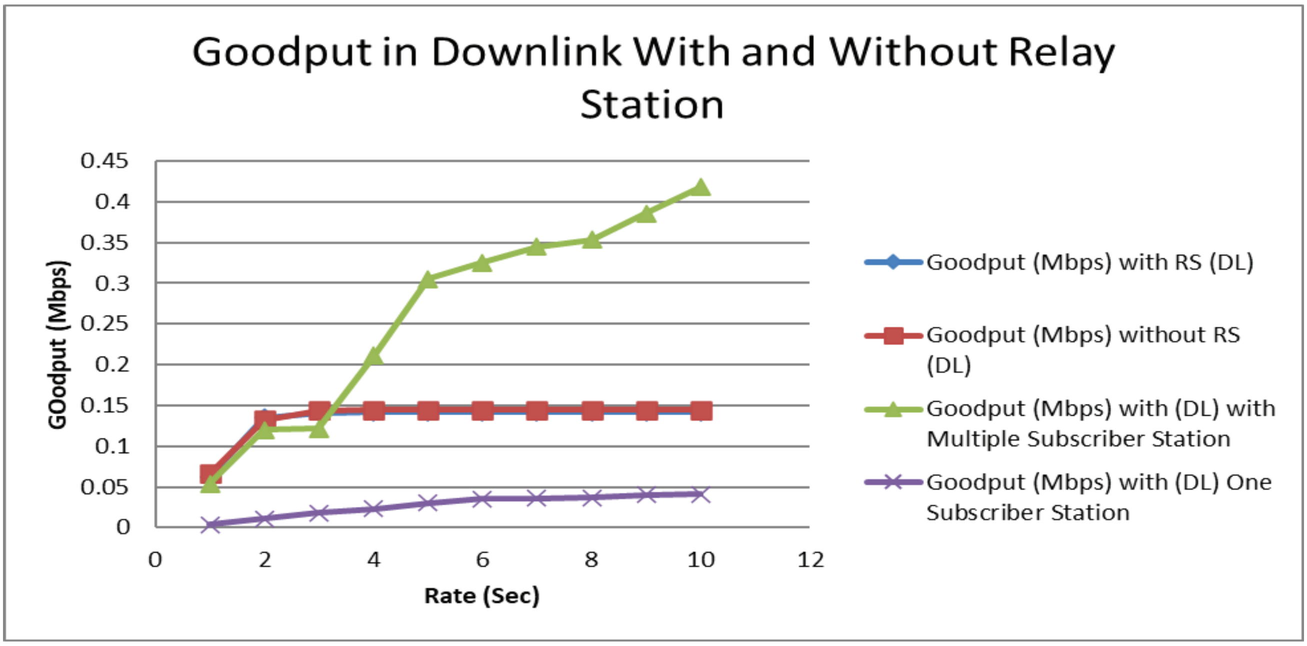

Figure 5. Goodput in downlink with and without relay stations in RTPS

- Goodput: Successfully received bytes at the destination.

$$Goodput = \frac{Packet\ Received * 8}{300} * 10^{-6} \quad (2)$$

- Packets Drop: Packet Drop: Total packets dropped during the communication duration.

$$Drop\ Rate = \frac{Number\ of\ Packets\ Dropped * 8}{Simulation\ Duration} * 10^{-6}\ Mbps \quad (3)$$

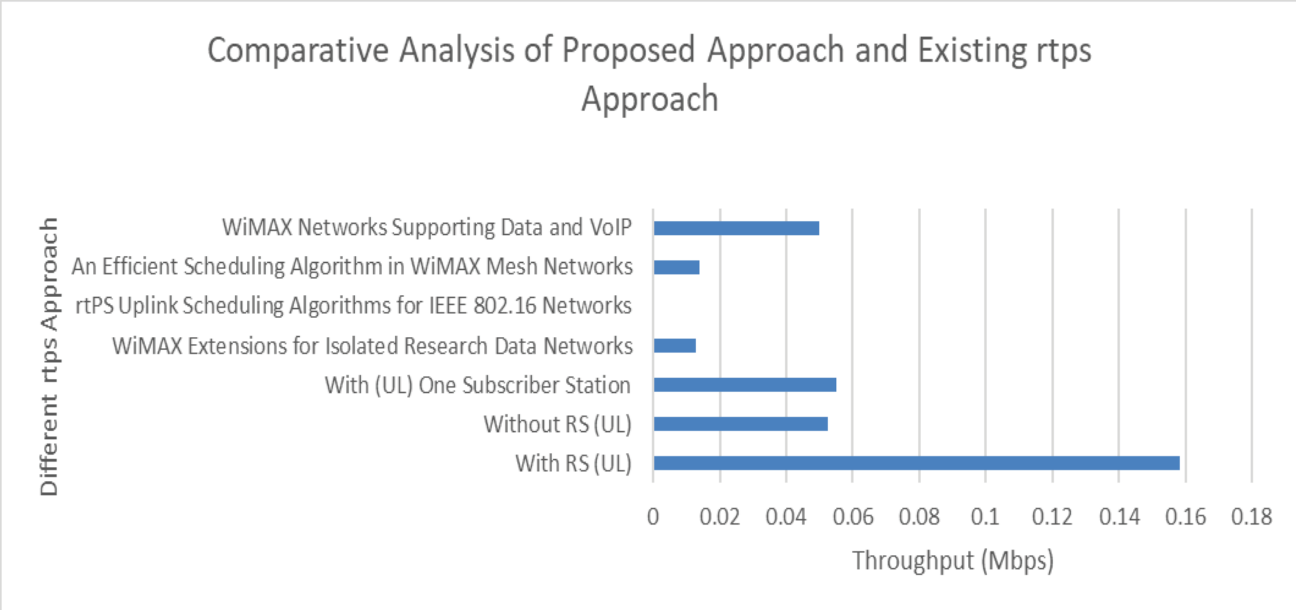

Figure 6. Comparative analysis of proposed approach with previous approaches

6. Results and Discussions

This section shows the results obtained by simulation and represented using graphs with justification. The performance of with relay station and without relay station is measured using throughput and goodput in uploading and downloading both. Also, the results show the performance with multiple subscriber stations and single subscriber station.

The throughput with rate in uplink transmissions is shown with and without relay station in Figure 2. The result shows that the with and without relay stations provide the best uplink transmission throughput of 0.16 Mbps, it is also observed that the throughput obtained with the multiple subscriber stations and single subscriber station is poorer than with and without relay station.

The graph further examines the relationship between rate and throughput: the higher throughput is seen when using a relay and without relay station, and this is because the channel is being used to its fullest potential. Throughput rises as more packets can travel over a given distance in a given amount of time in both situations of data packets.

Figure 3 depicts downlink throughput with and without relay stations. The graph compares the four scenarios: single subscriber station, multiple subscriber stations, without relay station, and with relay stations. The result shows that in case of downloading conditions, highest throughput is obtained in with multiple subscriber stations as rate increases. The results also show that after multiple subscriber stations, best results are obtained in with and without relay stations in downlink connections as rate increases. The performance is increased as rate increases due to the highest channel utilizations.

Figure 4 depicts uplink data transmissions in terms of packets received per second. Since data is received directly from base stations with maximum power and with full bandwidth utilization, it is observed from the analysis that higher goodput is observed with multiple subscriber stations as rate increases. Furthermore, it is also observed that on increasing rate goodput without relay station is observed second highest outputs than goodput with relay stations and lastly observed in in goodput with one subscriber station. As the time period increases in all the four cases, goodput is discovered to have increased as a result of increased rate since maximum packets are received on increasing rates.

Figure 5 shows that in case of downlink connections best results are observed in case of multiple subscriber stations as rate increases. After that is goodput without relay station gives better results than with one subscriber stations. In all the four cases it is observed that as rate increases the number of packets received per second also increases in case of downloading links. The analysis demonstrates that as rate rises, greater goodput is seen in terms of multiple subscriber stations: 0.05 Mbps for 1 second and 0.43 Mbps for 10 seconds. This work depicts that as rate increases, goodput also increases.

7. Conclusion

Both uplink and downlink connections are used to evaluate the RTPS performance of WiMAX networks in this work. When comparing this work with the previous research works, it is observed from the Figure 6 that the throughput in case of with relay station in uplink connections performs much better, which is observed to be 0.16 Mbps.

In all the scenarios, it is observed that uplink transmissions with relay station, without relay station, with single subscriber station performed much better than the previous works and downlink connections with multiple subscriber stations in the WiMAX networks. It is observed from the analysis that every time the rate increases the performance increases. Without relay stations, goodput in an uplink connection produces better outcomes. In case of downlink connections, with multiple subscriber stations goodput performs better. Throughput and goodput both increase as the rate increases. The comparative results show that the proposed RTPS service gives 68% better goodput than [6] and 91.33% better goodput than [2], while it shows 90.66% better goodput than [16] and 100% better goodput than [3].

8. Limitations and Future Work

The results are calculated with various cases considering one subscriber station and multiple subscriber stations but not limited to RTPS only. The results can be carried out with other quality of service parameters used in WiMAX networks like UGS (Unsolicited Grant Service), ERTPS (Extended Real Time Polling Service) and NRTPS (Non-Real Time Polling Services) at the later stage of work. The results can be calculated with other parameters like cyclic prefix and with different bandwidth allocation algorithms. The whole analysis could also be used in case of other WiMAX parameters for better performance in future.

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References

[1] "IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems," *IEEE Std 802.16-2004 (Revision of IEEE Std 802.16-2001)*. pp. 0_1-857, 2004. doi: 10.1109/IEEESTD.2004.226664.

[2] T. Bohnert, Y. Koucheryavy, M. Katz, E. Borcoci, and E. Monteiro, "Network Simulation and Performance Evaluation of WiMAX Extensions for Isolated Research Data Networks," *IEEE J. Commun. Softw. Syst.*, vol. 4, p. n/a, Mar. 2008, doi: 10.24138/jcomss.v4i1.238.

[3] E. M. Cenk and A. Nail, "rtPS Uplink Scheduling Algorithms for IEEE 802.16 Networks," in *Proceedings of Eighth International Symposium on Computer Networks (ISCN'08), ISBN: 978-975-518-295-7, Copyright ©2008 by Boğaziçi University*, 2008, pp. 141–147.

[4] S. Ghazal, L. Mokdad, and J. Ben-Othman, "Performance Analysis of UGS, rtPS, nrtPS Admission Control in WiMAX Networks," in *2008 IEEE International Conference on Communications*, 2008, pp. 2696–2701. doi: 10.1109/ICC.2008.509.

[5] C. So-In, R. Jain, and A.-K. Tamimi, "Scheduling in IEEE 802.16e mobile WiMAX networks: key issues and a survey," *IEEE J. Sel. Areas Commun.*, vol. 27, no. 2, pp. 156–171, 2009, doi: 10.1109/JSAC.2009.090207.

[6] I. Adhicandra, R. Garroppo, and S. Giordano, "Configuration of WiMAX Networks supporting Data and VoIP traffic," Aug. 2008. [Online]. Available: https://www.researchgate.net/publication/299366342_Configuration_of_WiMAX_Networks_supporting_Data_and_VoIP_traffic#fullTextFileContent.

[7] T. Raina, P. Gupta, B. Kumar, and B. L. Raina, "Downlink Scheduling Delay Analysis of rtps to nrtps and BE Services in WiMAX," *Int. J. Adv. Res. IT Eng.*, vol. 6, no. 2, pp. 47–63, 2013, [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://garph.co.uk/IJARIE/June2013/6.pdf.

[8] B. Kharthika and G. M. Vigneswari, "Improve WiMAX Network Performance Using Cross-Layer Framework," *Int. J. Sci. Eng. Res.*, vol. 4, no. 1, 2013, [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.ijser.org/researchpaper/Improve-WiMAX-Network-Performance-Using-Cross-Layer-Framework.pdf.

[9] A. Lygizou, S. Xergias, and N. Passas, "rtPS Scheduling with QoE Metrics in Joint WiMAX/Satellite Networks," P. Pillai, R. Shorey, and E. Ferro, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013, pp. 1–8. doi: 10.1007/978-3-642-36787-8_1.

[10] A. L. Yadav, P. D. Vyavahare, and P. P. Bansod, "Review of WiMAX Scheduling Algorithms and Their Classification," *J. Inst. Eng. Ser. B*, vol. 96, no. 2, pp. 197–208, 2015, doi: 10.1007/s40031-014-0145-5.

[11] D. M. S. Madhuri, D. Reethu, C. K. Mani, and T. A. V. S. S. N. Raju, "Service Prioritized Opportunistic Scheduling Algorithm for WiMAX Mobile Multi-Hop Relay Networks," *Int. J. Eng. Res. Technol.*, vol. 03, no. 02, pp. 2274–2279, 2014, [Online]. Available: https://www.ijert.org/research/service-prioritized-opportunistic-scheduling-algorithm-for-wimax-mobile-multi-hop-relay-networks-IJERTV3IS21432.pdf.

[12] R. A. Talwalkar and M. Ilyas, "Analysis of Quality of Service (QoS) in WiMAX networks," in *2008 16th IEEE International Conference on Networks*, 2008, pp. 1–8. doi: 10.1109/ICON.2008.4772615.

[13] P. Sapna and D. Priyanka, "Optimizing IEEE 802.16j: Multihop Relaying in WiMAX Networks," *Int. J. Eng. Trends Technol.*, vol. 19, no. 1, pp. 24–28, 2015, [Online]. Available: https://ijettjournal.org/assets/volume/volume-19/number-1/IJETT-V19P206.pdf.

[14] N. N. Alfaisaly, S. Q. Naeem, and A. H. Neama, "Enhancement of WiMAX Networks using OPNET Modeler Platform," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 23, no. 3, pp. 1510–1519, 2021, doi: http://doi.org/10.11591/ijeecs.v23.i3.pp1510-1519.

[15] S. S B, S. M S, S. Pathak, S. Irfan, and R. H, "Analysis Of Scheduling Algorithm in WiMAX Network," *J. Emerg. Technol. Innov. Res.*, vol. 6, no. 6, pp. 414–418, 2019, [Online]. Available: https://www.jetir.org/papers/JETIR1906A64.pdf.

[16] C.-Y. Chang, M.-H. Li, W.-C. Huang, and C.-C. Chen, "An Efficient Scheduling Algorithm for Maximizing Throughput in WiMAX Mesh Networks," in *Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly*, 2009, pp. 542–546. doi: 10.1145/1582379.1582497.

[17] K. J. Kim and B. D. Choi, "Performance Analysis of Extended RtPS Algorithm for VoIP Service by Matrix Analytic Method in IEEE 802.16e with Adaptive Modulation and Coding," 2009. doi: 10.1145/1626553.1626564.

[18] B.-J. Chang, Y.-H. Liang, and S.-S. Su, "Analyses of QoS-based relay deployment in 4G LTE-A wireless mobile relay networks," in *2015 21st Asia-Pacific Conference on Communications (APCC)*, 2015, pp. 62–67. doi: 10.1109/APCC.2015.7412581.

[19] J. M. M�rquez-Barja, C. T. Calafate, J.-C. Cano, and P. Manzoni, "Evaluating the Performance Boundaries of WI-FI, WiMAX and UMTS Using the Network Simulator (Ns-2)," in *Proceedings of the 5th ACM Workshop on Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks*, 2010, pp. 25–30. doi: 10.1145/1868612.1868618.

[20] H. M. Ismail and M. I. Ashour, "Analysis and Design of IEEE 802.16 Uplink Scheduling Algorithms and Proposing the IRA Algorithm for RtPS QoS Class," in *Proceedings of the 6th ACM Workshop on Wireless Multimedia Networking and Computing*, 2011, pp. 49–54. doi: 10.1145/2069117.2069127.

[21] B. Al-Madani, M. Al-Saeedi, and A. A. Al-Roubaiey, "Scalable Wireless Video Streaming over Real-Time Publish Subscribe Protocol (RTPS)," in *2013 IEEE/ACM 17th International Symposium on Distributed Simulation and Real Time Applications*, 2013, pp. 221–230. doi: 10.1109/DS-RT.2013.32.

[22] R. C. Garcia, B. S. Reyes Daza, and O. J. Salcedo, "Evaluation of Quality Service Voice over Internet Protocol in WiMAX Networks Based on IP/MPLS Environment," in *Proceedings of the 11th ACM Symposium on QoS and Security for Wireless and Mobile Networks*, 2015, pp. 59–66. doi: 10.1145/2815317.2815322.

[23] R. Underwood, J. Anderson, and A. Apon, "Measuring Network Latency Variation Impacts to High Performance Computing Application Performance," in *Proceedings of the 2018 ACM/SPEC International Conference on Performance Engineering*, 2018, pp. 68–79. doi: 10.1145/ 3184407.3184427.

[24] A. Busch and M. Kammerer, "Network Performance Influences of Software-Defined Networks on Micro-Service Architectures," in *Proceedings of the ACM/SPEC International Conference on Performance Engineering*, 2021, pp. 153–163. doi: 10.1145/3427921.3450236.

[25] "The Network Simulator - Ns-2," 2022. https://www.isi.edu/nsnam/ns/ (accessed Jun. 18, 2022).