International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8, Issue-1S4, June 2019

A Cross Layer based Bandwidth Management scheme for Next Generation Wireless Networks

G Rajesh, P. Venkata Krishna

ABSTRACT--- As the bandwidth is a scarce resource, efficient mechanisms are required to efficiently use the available bandwidth. Hence, in this paper, cross layer-based bandwidth management for next generation wireless networks (CLBMS) is proposed. Network layer and the application layer are used to design the cross-layer architecture. Various types of services classified as Service level, SL 1, SL 2, and SL 3 with highest priority for SL 1 followed by SL 2 and SL 3 are considered in the case of application layer. Bandwidth and delay are the parameters considered in the case of the network layer. The database that can be shared is utilised to access the parameters amid various layers in the network. The proposed algorithm, CLBMS is implemented and assessed for the parameters, total flow acceptance, probability of the originating calls that gets blocked and probability of the handoff calls that gets dropped. The performance of the proposed algorithm, CLBMS is compared with Adaptive Bandwidth Binning for bandwidth management (ABB) scheme and proved to be performing better.

Keywords—cross layer, bandwidth management, wireless network, blocking probability, dropping probability.

1. INTRODUCTION

A wireless framework is a versatile data correspondences structure, which uses wireless media, for instance, radio frequency to transmit and receive data over the wireless media, i.e, air, constraining the prerequisite for wired affiliations. Wireless structures use electromagnetic waves to impart information preliminary by means of one point before onto the following deprived of relying upon any physical connection. Radio waves are normally insinuated as radio transporters since they basically behave deprived of the limit of conveying energy to a distant authority. The data being imparted is overlaid on the radio transporter so it tends to be precisely mined at the destination side. At the point when data is overlaid (adjusted) onto the radio transporter, the sign of radio includes more than a recurrence, as the recurrence or bit rate of the altering information augments to the transporter. Different radio transporters can be in a comparable space meanwhile without intruding with each other if the radio waves are conveyed on different radio frequencies. To mine data, a destination of radio tunes in a single frequency of radio while dismissing every other frequency. Demodulation process is carried out on the modulated signal to separate the information from the signal.

Scalability, diminished expense of proprietorship, greater adaptability, reach of the system, establishment speed and straightforwardness and portability are the benefits of wireless systems when compared to wired systems. Presently, as of now the prevalent wireless technologies being utilized are: "WiFi, Bluetooth, ZigBee, NFC, WiMAX, LTE, HSPA, EV-DO", previous 3G models, satellite administrations, etc. All things considered, given the assorted variety, it isn't astute to make clearing assumptions about the behaviour of wireless systems. In any case, fortunately most wireless improvements work on basic ideals, have regular exchange offs, and are legally responsible to basic implementation principles and imperatives.

There are different types of wireless networks which vary in the range of the signal and standards. Various wireless networks are Personal Area Network (PAN), Local Area Network (LAN), Metropolitan Area Network (MAN), Wide Area Network (WAN). The coverage area of PAN is 10 meters. PAN is used to connect the devices fixated on a distinct individual's workspace. This network is used to connect various devices like computers, tablets, smart phones, etc. Ex: Bluetooth, IRDA, ZigBee, Wireless USB etc. Local Area Network (LAN) is used all the system which are in one building that covers 100 meters range and it is also possible to connect the systems in one campus using LAN that covers 1000 meters range. It is used to extend the wired network using wireless network. Ethernet (IEEE 802.3), WiFi (IEEE 802.11), etc are the standards of LAN. The coverage area of MAN is around 50 Kms. The systems in one city can be covered using MAN. Various wireless networks can be interconnected using MAN. IEEE 802.15 is one of the standards of MAN. All the systems throughout the world can be connected using WAN.

Wireless network access is possible in WAN. Cellular networks (UMTS, LTE, etc.) are the standards of WAN.

Bandwidth in wireless networks [1-11] is a rare asset. It is shared by numerous remote nodes which are in the region of one another. A few nodes may overwhelm the channel and some may not get enough data transfer capacity for their administration necessity. In this manner, appropriate

Revised Manuscript Received on June 10, 2019.

G Rajesh, Research Scholar, Department of Computer Science Rayalaseema University, Kurnool, AP, India. (E-mail:rajesh.audisankara@gmail.com)

P. Venkata Krishna, Senior Member IEEE, Department of Computer Science, Sri PadmavatiMahila University, Tirupati, A.P, India. (E-mail: pvk@spmvv.ac.in)

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

systems ought to be set up to deal with the data transmission. Management of bandwidth [4, 5] includes productive usage of transmission capacity by appropriate channel distribution, diminishing undesirable traffic, approximating existing bandwidth, observing the wireless channel, adjusting the stream and rate, ensuring QoS and so on [11, 12].

The distinctive difficulties to give QoS in wireless systems consists of changing channel qualities, transfer speed and adaptation to non-critical failure points. The style of offering QoS by various layers in the protocol stack is different from layer to layer. The system will be increasingly adaptable and lenient to QoS problems just once QoS is ensured in each layer. In cellular systems, bandwidth is the most important parameter in giving QoS. Bandwidth need to be proficiently dispensed as its accessibility is constrained. At the point when various types of traffic like real-time and non-real-time are to be reinforced, it turns out to be increasingly intricate. Ongoing traffic do tolerate interruption. So, they require quick reaction immediately where as non-real-time traffic are less deferring delicate yet do not tolerate loss of information. Non-real-time traffic assumes parcels without any error. While delivering QoS to real-time and non-real-time traffic, all these issues should be thought about [4, 5, 13-19].

By and large, the layers in the system are composed in sequence. The administrations to be accessible by the system are divided or partitioned and allocated to various layers. Along these lines of task of administrations to various layers makes the particulars of the application of services of lower layer to be straightforward to the next level layers and the system intricacy is diminished. This is otherwise called organized methodology which gives simple calibration, interoperability among layers and shared connections among various systems [1]. In this ordinary and organized methodology, the conventions of different layers associate strongly.

The Cross-layer configuration is a straightforward adjustment to the current organized methodology yet not so much extraordinary and in the meantime keeps up the qualities of a layered methodology. The sharing of data among various layers in the protocol stack is the fundamental goal of the cross-layer configuration [20].

Diversed cross layer configuration methods are [21]:

- The lower level layer parameters can be communicated to the higher level layer and vice-versa with the introduction of new interface that can communicate with both the layers.
- Also, the newly created interface can be used to share the data among various layers at runtime.
- Two or more layers adjacent to each other can be combined to form a new layer. Consequently, the limits amid consolidated layers are deleted. No requirement of creating a new interface. Much distinction do not exists between the organized methodology and the cross layer configuration as indicated by this methodology yet the main contrast is the layers count will be decreased.
- In third approach, two layers are characterized as fixed layer and designed layer. The configuration of the designed layer configuration is to be adjusted by the procedure of the fixed layer. In this way, there is no compelling reason to make any new interface.
- Tuning of layer vertically – the lower layers paramter values determine the behaviour of the layers above it.

The immediate correspondence amid layers can be actualized by cross layer configuration. Otherwise, a database is designed that can be utilized by all the layers or through characterization of totally novel deliberations [21].

2. RELATED WORK

In [22], a novel procedure which saves power is proposed along with the consistent protocol referred as WiFi in Zizz (WiZizz). The channel bonding characterised in IEEE 802.11 ac is cautiously exploited. The bandwidth of the channel is effectively utilized based on the request when required to decrease the awful energy consumed by IEEE 802.11 ac devices. The authors claim that the proposed procedure saves 73% of energy when simulation is carried out over a wide scope of correspondence situations. WiZizz is the first and foremost protocol which is affable and manages the bandwidth effectively and conserves energy whereas the procedures that prevailing need expensive alterations to the description of IEEE 802.11ac.

In [23], a novel data transfer capacity the board plot referred as Adaptive Bandwidth Binning (ABB) is proposed.

Despite the fact that ABB has clear relevance to downstream administration, it is displayed with regards to a DOCSIS link organization. All downstream traffic is planned by a solitary headend gadget utilizing shared medium access organization, for example, a CMTS or passage or remote BS. ABB is fit for giving rough biased maximum-minimum reasonable distribution of downstream data transfer capacity by means of a truncated-above scheduler which needs just few for all time designated lines. A cutting-edge delay-based dynamic line the board (AQM) system is utilized to governor interruptions. The execution of ABB is assessed by means of ns-2 recreations in which outstanding tasks at hand incorporate FTP, HTTP-based adaptive streaming (HAS), and web traffic focused for various layered administration excellence dimensions. Outcomes demonstrate that ABB can give inexact weighted max-min reasonable transmission capacity assignment among responsive high data transfer capacity streams while separating them from low transmission capacity and inactivity touchy streams. The utilization of CoDel in every ABB line is successful in overseeing inertness as essential. The utilization of stream loads in ABB underpins administration levelling where supporters wage additional for developed administration charges.

The structure and assessment of a bandwidth distribution procedure [24] dependent on multiple ware stream issue solver coordinated with a circulation indicator: “linear predictor with dynamic error compensation” (L-PREDEC). The fundamental thought of the structure is that approximately disappointment in the MFP calculation infers that at least one connection don't have enough accessible limit, which abuses the direct limitations on the wares for each connection when demonstrating MFP. To abstain from delivering bottleneck joins, traffic indicator is utilized. On one hand, MFP solver improves asset use by utilizing the slim bits of accessible transfer speed, by which the virtual system can acknowledge more administration demands. Then again, the traffic indicator modifies the connection with the biggest profession (bottleneck interface) by occasionally checking the circulation frequency of a client interface and altering the held transfer speed dependent on the forecast produced using the traffic history. At that point the aftereffects of execution correlations of the indicator coordinated calculation and the designation calculation just by Solving MFP are exhibited. The correlations depend on the average packet delay, the change of the parcel delay, and the support necessities. The execution tests demonstrate that indicator coordinated calculation works superior to the distribution calculation just by Solving MFP as far as the three measurements recorded previously.

An adaptive bandwidth management and joint call admission control (JCAC) scheme for heterogeneous cellular networks is proposed in [25]. The goals of the proposed versatile JCAC plot are to improve normal framework use, ensure QoS prerequisites of every single acknowledged call, and lessen the possibility of originating calls being blocked and possibility of handoff calls being dropped in assorted wireless systems. A Markov chain demonstrate for the versatile JCAC system and possibility of originating calls being blocked and possibility of handoff calls being dropped and normal framework usage are determined. Execution of the projected versatile JCAC system is contrasted and that of non-adaptive JCAC conspire in the equivalent assorted wireless system. Outcomes demonstrate an enhancement in normal framework use almost 20%. Outcomes likewise demonstrate that association level QoS can be essentially enhanced by utilizing the projected versatile JCAC system.

Fair Queuing (FQ) was initially projected by Nagle [27] and after that reached out by several others. These expansions establish a class of systems that manages bandwidth and are fit for giving extreme stream confinement and max-min fairness. Be that as it may, these frameworks require a different line for each stream. Thusly, both stream and management of queue are intricate. The fundamental scheduling procedures can be extensively separated into 2 classifications: procedures grounded on round or outline and time-stamp. Fluid Flow Model is the basis for the perfect reasonable queuing procedure referred as "Generalized Processor Sharing (GPS) [28]. The aforementioned expects the circulation to be unendingly distinct. Along these lines, GPS can serve a discretionarily little measure of information to each accumulated stream inside any limited time interim. GPS in this way can give perfect segregation of flows and fairness. GPS, in any case, isn't implementable in light of the fact that real packets convey limited header additional loaded and aren't limitlessly isolatable. The weighted Fair Queuing (WFQ) framework [29] approaches GPS aimed at limited measured packets. It keeps up a simulated period timer and ascertains a simulated timestamp /service label for every packet. The development module chooses the packet with the least service label to communicate.

In order to deal the unpredictability issue with WFQ, Golestani built up self-clocked fair queuing (SCFQ) procedure [30]. Rather than utilizing the simulated period obtained from GPS framework for the figuring of administration labels, SCFQ utilizes the administration label of the packet presently getting facility as an approximation of the framework simulated period. The close ideal behaviour is maintained and yet essentially improves the calculation of administration labels. It likewise decreases the intricacy to O (log n) effort per packet, that is the measure of period needed aimed at the arrangement of administration labels.

Every stream need on queue to be maintained if the approach is round-robin [27]. Circular list of queue descriptors is maintained by the scheduler. The packet is selected from the queue which is not empty on the list during the scheduling process. The truncated unpredictability of O (1) is accomplished by maintaining strategic distance from the arrangement holdup of a period stamp grounded method. But the method is unfair in terms of throughput when the size of the packet is varied.Deficit Round Robin (DRR) [26] rectifies this injustice. The number of bytes that can be communicated for every round in the scheduling process can be restricted using the framework metric. The deficit counter that is maintained for every queue is instated to 0. For every backlogged queue, the number of bytes that can be communicated for every round in the scheduling process is summed to the deficit counter at the start of every round. When the packets from the queue are transmitted, then the corresponding length is decreased from the corresponding queue's deficit counter. The next backlogged queue is processed when the queue which is being processed becomes empty or becomes negative when the deficit counter is decremented for the number of transmitted packets. Maximum-minimum throughput fairness is attained by DRR to a particular breaking point. But this breaking point is higher when compared to the extreme distinction between genuine parcel communication period in contrast to GPS and grounded on simulated communication period.

3. CROSS LAYER BASED BANDWIDTH MANAGEMENT SCHEME (CLBMS)

The cross-layer architecture is developed using the application layer and the network layer as shown in Fig. 1. The strategy depends on the division of the features of network into two categories. Application Layer Features (ALF) and Network Layer Features (NLF). The ALF characterizes the grouping of the traffic type in the various service levels that will be utilized by the system, for example, SL 1, SL 2, and SL 3 services. The priority of the services of SL 1, SL 2 and SL 3 are in decreasing order, which indicates the SL 1 has highest priority and SL 3 has least priority. The priority of SL 2 service lies between SL 1 and SL 3. The data related to the optimal paths and secondary paths, reassignment of priorities among various levels of services and

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

bandwidth is given by NLF. Shared database is used to employ the cross layer design. The details about different layers like ALF and NLF are stored in the shared database. The essential QoS for a particular application is chosen using these features and also these features are retrieved before messaging by different layers when required from the shared database. The details of different services that can be provided by application layer for various applications are stored in ALF. Level of QoS and level of service requested are used to determined the service to be provided for the application. The details related to QoS are obtained from the information stored in the form of ALF in the shared database and the details of other features. The ALF structure is described as (SL, Service Class, Movement). Bandwidth and delay parameters are considered for the selection of the optimal path. The details related to the node, bandwidth and delay are stored in the form of NLF structure. The NLF structure is described as (Node_ID, Routing Table (route, delay, bandwidth)).

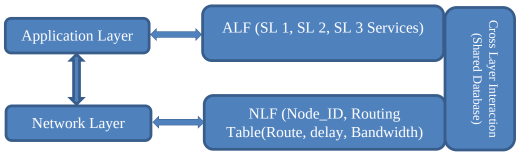

Fig. 1 Cross Layer Architecture

When the number of flows request for the bandwidth to start the communication, then the ALF services determine the type of service based on which the priority of the flow is known. The bandwidth requirement for each flow is considered. Multiple paths are determined based on the bandwidth required. The physical layer provides the information related to the strength of the signal of the nodes in the system. Multiple paths are determined using which the communication is carried out. The nodes in these paths must have the better signal strength when compared to the threshold value. Node disjoint paths among these determined multiple paths are chosen for corresponding sender and receiver nodes. The remaining bandwidth that can be used for the communication purpose of a particular path is calculated by obtaining the required information of each connection in the path from the MAC layer. The remaining bandwidth of a particular route is the minimum remaining bandwidth amid all the connections in the corresponding route. The remaining bandwidth must be sufficient for the communication to be carried out. This is determined using the required bandwidth for the communication process that is obtained from the application layer. The ultimate routes that can be used for communication process are those whose remaining bandwidth is more than the required bandwidth.

The bandwidth is updated in order to make the admission control method to be adaptive for the bandwidth changes. When a new application requests for a service, it is added. When the old service requested by a particular application need to be changed to receive either upper level of service or lower level service, update operation is performed. Once the service is to be stopped for any application then delete operation is carried out. These modifications are made using the following equation.

$$BW_{remaining} = BW_{Total} - \sum_{i=0}^{N} \sum_{j=0}^{L_N-1} R_{min}(i,j) \qquad (1)$$

Where $BW_{remaining}$ is the remaining bandwidth, BW_{Total} is the total available bandwidth in the system, N is the number of levels of services that can be provided, L_N links available in the network and $R_{min}(i, j)$ is the bandwidth reserved for providing the i^{th}service to the L_N^{th} link.

4. RESULTS AND DISCUSSION

Poisson distribution is used to organize the arrival of service streams homogeneously. The stream is transmitted only after the receipt of the acknowledgment. The possibility with which the handoff calls drop and the possibility with which the originating calls are blocked is estimated periodically. The simulation started with a total 150 different service flows comprised both new and handover traffics. The performance of the projected procedure, CLBMS is implemented and assessed with respect to total flow acceptance, the possibility with which the handoff calls drop and the possibility with which the originating calls are blocked. The behaviour with respect to total flow acceptance is shown in Fig. 2, blocking probability is shown in Fig. 3, and dropping probability is shown in Fig. 4. The CLBMS is designed using cross layer technique which helps in reserving the bandwidth efficiently for the required flows which is the main reason for the better performance when compared to Adaptive bandwidth binning for bandwidth management (ABB). For implementation persistence, the number of cells in the system are taken as 15, arrival rate of SL 1 requests is considered to be 12 requests/s, arrival rate of SL 2 requests is considered to be 20 requests/s, arrival rate of SL 3 requests are taken as 5 requests/s and the frequency of the service being provided is dynamic depending on the position of the system. The speed with which the nodes move is considered to be 20 m/s. It can be observed from Fig. 2 – Fig. 4, that the performance of the proposed algorithm, CLBMS is better when compared to ABB.

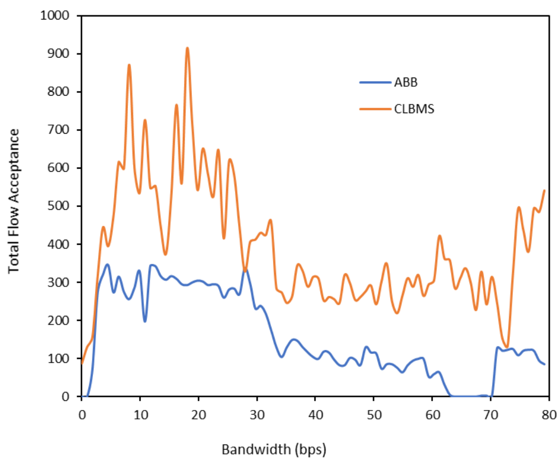

Fig. 2 Bandwidth Management for 300 flows

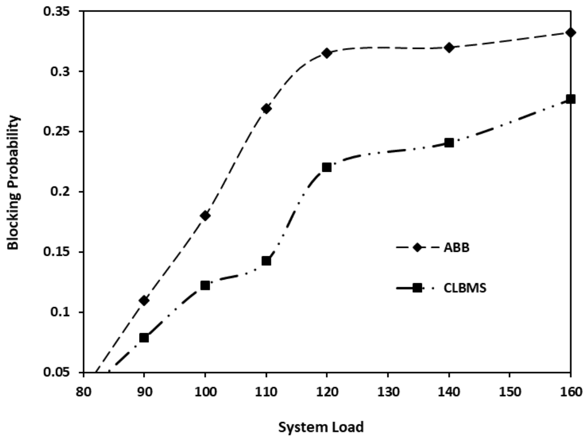

Fig. 3 Blocking Probability vs System Load

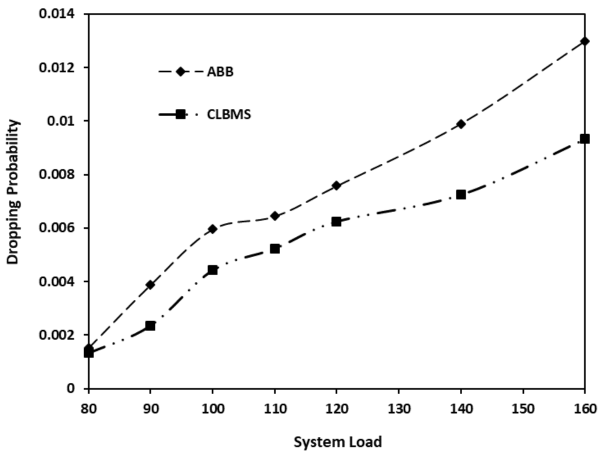

Fig. 4 Dropping Probability vs System Load

5. CONCLUSION

Cross layer-based bandwidth management for next generation wireless networks is proposed in this paper. The cross-layer architecture is designed based on the network layer and the application layer. The level of services and mobility are considered as parameters from the application layer and the bandwidth and delay are considered as parameters from the network layer. The database that can be shared is utilised to access the parameters amid various layers in the network. Bandwidth update expression is used to determine the flows which acquire the required bandwidth and start the communication. The performance of the projected procedure, CLBMS is implemented and assessed with respect to total flow acceptance, the possibility with which the handoff calls drop and the possibility with which the originating calls are blocked. The performance of the proposed algorithm, CLBMS is compared with Adaptive Bandwidth Binning for bandwidth management (ABB) scheme and proved to be performing better.

REFERENCES

1. Krishna, P., & Iyengar, S. (2007). A cross layer based QoS model for wireless and mobile ad hoc networks. *Mobile Communication*, *1*, 114-120.
2. Krishna, P. V., Obaidat, M. S., Misra, S., & Saritha, V. (2009, May). An efficient 802.11 medium access control method and its simulation analysis. In *2009 IEEE/ACS International Conference on Computer Systems and Applications* (pp. 330-335). IEEE.
3. Misra, S., Krishna, P. V., & Saritha, V. (2012). LACAV: an energy-efficient channel assignment mechanism for vehicular ad hoc networks. *The Journal of Supercomputing*, *62*(3), 1241-1262.DOI: 10.1007/s11227-011-0552-1
4. Misra, S., Krishna, P. V., & Saritha, V. (2012). An efficient approach for distributed channel allocation with learning automata-based reservation in cellular networks. *Simulation*, *88*(10), 1166-1179. Doi: 10.1177/0037549711420175
5. Venkata Krishna, P., Misra, S., Obaidat, M. S., & Saritha, V. (2009, March). A new scheme for distributed channel allocation in cellular wireless networks. In *Proc. of 12th ACM/SCS Communications and Networking Simulation Symposium (CNS), San Deigo, USA* (pp. 22-27).
6. Misra, S., Krishna, P. V., & Abraham, K. I. (2011). Learning automata solution for medium access with channel reservation in wireless networks. *Wireless Personal Communications (WPS), Springer*, *56*(1), 55-72.
7. Krishna, P. V., Misra, S., Obaidat, M. S., & Saritha, V. (2009). Virtual backoff algorithm: An enhancement to 802.11 medium-access control to improve the performance of wireless networks. *IEEE Transactions on Vehicular Technology*, *59*(3), 1068-1075.
8. Krishna, P. V., Misra, S., Obaidat, M. S., & Saritha, V. (2009). An efficient approach for distributed dynamic channel allocation with queues for real-time and non-real-time traffic in cellular networks. *Journal of Systems and Software*, *82*(7), 1112-1124. (Elsevier) DOI: 10.1016/j.jss.2009.01.043
9. Misra, S., Krishna, P. V., Bhiwal, A., Chawla, A. S., Wolfinger, B. E., & Lee, C. (2012). A learning automata-based fault-tolerant routing algorithm for mobile ad hoc networks. *The Journal of Supercomputing*, *62*(1), 4-23. Doi: 10.1007/s11227-011-0639-8
10. Krishna, P. V., Iyengar, N. C. S., & Misra, S. (2008). An efficient Hash Table-Based Node Identification Method for bandwidth reservation in hybrid cellular and ad-hoc networks. *Computer Communications*, *31*(4), 722-733.
11. Krishna, P. V., & Iyengar, N. C. S. (2008). Optimal channel allocation algorithm with efficient channel reservation for cellular networks. *International Journal of Communication Networks and Distributed Systems*, *1*(1), 33-51.
12. Krishna, P. V., & Iyengar, N. C. S. (2008). Sequencing technique: an enhancement to 802.11 medium access control to improve the performance of wireless networks. *International Journal of Communication Networks and Distributed Systems*, *1*(1), 52-70.
13. Saha, M., & Krishna, P. V. (2012). Bandwidth Management Framework for Multicasting inWireless Mesh Networks. *International Journal of Information and Electronics Engineering*, *2*(3), 421.
14. Iyengar, N. C. S., & Venkata Krishna, P. (2008). Design of sequencing medium access control to improve the performance of wireless networks. *Journal of computing and information technology*, *16*(2), 81-89.
15. Krishna, P. V., Iyengar, N. C. S., & Misra, S. (2007, November). An approach for bandwidth reservation in ad-hoc networks having infrastructure support. In *Proceedings of the 7th Conference on 7th WSEAS International Conference on Applied Computer Science* (pp. 409-415).
16. H. Balakrishnan, V. Padmanabhan, S. Seshan, and. Katz." A comparison of mechanisms for improving TCP performance over wireless links". In Proceedings of ACM SIGCOMM'96, Stanford, California, Aug. 1996.
17. IEEE 802.11WG, Part 11:Wireless LAN medium access control (MAC) and physical layer (PHY) specifications, Standard, Aug. 1999.
18. F. Tobagi and L. Kleinrock, "Packet Switching in Radio Channels: Part II — The hidden Terminal Problem in Carrier Sense Multiple-Access Modes and the Busy-Tone Solution," IEEE Trans. Net., vol. 23, no. 12, 1975, pp. 1417–33.

Retrieval Number: A11850681S419/19©BEIESP

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

19. Z. Fu, P. Zerfos, H. Luo, S. Lu, L. Zhang, M. Gerla "The Impact of Multihop Wireless Channel on TCP Throughput and Loss," Proc. IEEE INFOCOM, San Francisco, USA, Apr. 2003.

20. Rolf Winter and Jochen H. Schiller, FreieUniversität Berlin. (2006).CrossTalk: cross-layer decision support based on global knowledge, IEEE Communications Magazine, Vol. 44, Issue 1, pp.93 – 99.

21. V. Srivastava, M. Motani. (2005). Cross-layer design: a survey and the road ahead, IEEE Communications Magazine, vol. 43, no.12, pp. 112–119.

22. Lee, O., Kim, J., & Choi, S. (2015, June). Wizizz: Energy efficient bandwidth management in ieee 802.11 ac wireless networks. In *2015 12th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON)* (pp. 136-144). IEEE.

23. Hong, G., Martin, J., & Westall, J. (2019). Adaptive bandwidth binning for bandwidth management. *Computer Networks*, *150*, 150-169.

24. Wei, Y., Wang, J., & Wang, C. (2010, November). A traffic prediction based bandwidth management algorithm of a future internet architecture. In *2010 Third International Conference on Intelligent Networks and Intelligent Systems* (pp. 560-563). IEEE.

25. Falowo, O. E., & Chan, H. A. (2007). Adaptive bandwidth management and joint call admission control to enhance system utilization and QoS in heterogeneous wireless networks. *EURASIP Journal on Wireless Communications and Networking*, *2007*(3), 2.

26. M. Shreedhar , G. Varghese , Efficient fair queuing using deficit round-robin, IEEE/ACM Trans. Netw. 4 (3) (1996) 375–385 .

27. J. Nagle , On packet switches with infinite storage, Commun. IEEE Trans. 35 (4) (1987) 435–438 .

28. A.K.J. Parekh , A Generalized Processor Sharing Approach to Flow Control in In- tegrated Services Networks, 1992 Ph.D. thesis.

29. A. Demers , S. Keshav , S. Shenker , Analysis and simulation of a fair queueing al- gorithm, in: ACM SIGCOMM Computer Communication Review, 19, ACM, 1989, pp. 1–12.

30. S.J. Golestani , A self-clocked fair queueing scheme for broadband applications, in: INFOCOM'94. Networking for Global Communications., 13th Proceedings IEEE, IEEE, 1994, pp. 636–646 .