Resource Optimization for Converging Wireless Networks

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***Abstract*-Next generation wireless networks are evolving from the inter-working of existing wireless networks. The inter-working of these networks conveniently brings about ubiquitous broadband internet access required by network users. However, the major concerns in inter-working wireless networks include how to ensure effective resource dimensioning and quality of service (QoS) provisioning while optimizing the overall network's resources. Although Traffic Engineering (TE) frameworks are used to overcome such network issues, a few of these frameworks are suitable for wireless networks. More so, there is virtually no TE framework for inter-working wireless networks. In addition most TE frameworks focus only on network layer metrics, which makes them inapplicable to wireless networks. Due to the stochastic nature of wireless networks, TE frameworks which capture metrics that affects QoS from other layers of the network are needed. Hence, this paper proposes a Multi-layer TE framework for QoS provisioning, resource dimensioning and optimization in inter-working wireless networks. The proposed framework is based on Stochastic Network Calculus.**

***Index Terms*—Inter-working, Traffic Engineering, Wireless Networks.**

I. INTRODUCTION

The success of wireless access networks and the rapid growth of the Internet have resulted in an increase in demand for wireless broadband Internet access. An advantage of the wireless broadband is that it is less expensive and easier to deploy than the wire-line broadband technologies [1]. Today, these wireless access networks such as the IEEE 802.11 WLAN (Wireless LAN) standards, IEEE 802.15 Wireless PAN (Personal Area Network), IEEE 802.16 (WiMAX), Adhoc networks, Sensor Networks, and Cellular networks are competing with the wired networks. However, most of these networks have limited capacity and coverage area [2]. To improve their potentials, next-generation wireless networks are evolving from the existing wireless networks through convergence and inter-working. The advantages of inter-working these wireless networks cannot be overemphasized.

Firstly, inter-working creates a larger service area coverage, increased network capacity and reliability. Also, inter-working facilitates a seamless fusion and inter-operation between the wireless networks. Secondly, though the competition between wireless networks and other broadband technologies is stiff, inter-working several wireless networks provides a viable lower cost alternative. Lastly, inter-working provides ubiquitous and less complex Internet access to users. It also eases the provisioning of Internet access in areas with no initial wire-line network coverage.

Despite all these benefits, the inter-working of different wireless networks poses several challenges. Two of these challenges are how to effectively;

1) Optimize the provisioning of QoS to all traffic traversing the resulting inter-worked network.
2) Optimize the dimensioning of network's resources.

To tackle these challenges, a new way of performing traffic engineering is needed for inter-working wireless networks. This new approach involves developing a TE framework, which jointly captures metrics that affects QoS on the three lower layers of the network stack (e.g. physical, MAC and network layers). Therefore, this paper proposes a Multi-layer TE framework which captures metrics (from the physical, MAC and network layers) that affects QoS in Inter-working wireless networks. A multi-layer solution is proposed because each layer in the network contributes to the end-to-end QoS experienced by a network-user. Accordingly, a multi-layer framework allows resources on the physical and MAC and network layers to be jointly dimensioned and optimized. The purpose of the Multi-layer TE framework is to enable effective QoS provisioning and resource dimensioning while optimizing network resources. It deals with the dimensioning of network resources as traffic move from one wireless network to another.

The content of this paper is organized as follows: section II summarizes the challenges of traffic engineering in inter-working wireless networks. Section III discusses the need for a multilayer TE framework for Inter-working wireless networks. The proposed Multi-layer TE framework and the model of the Inter-working wireless network are given in section IV while section V concludes the paper.

II. CHALLENGES OF TRAFFIC ENGINEERING IN INTERWORKING WIRELESS NETWORKS

The objective of any operational network is to satisfy the network user's need and the service providers' need. Fundamentally, a user requires a degree of service quality from the network. Also, a service provider needs satisfactory returns on investment for the resources utilized to meet the user's need. Therefore an optimal network performance is necessary in order to mutually satisfy the users and service providers. The application of traffic engineering (TE) concepts to networks helps to achieve a balance between these two needs. TE achieves a balance by ensuring that QoS is delivered to end-users while optimizing and managing network's resources economically. More specifically, TE allows a network to choose routes for traffic while taking into account traffic loads and network state, to move traffic towards less congested paths. It also allows the network to timely react to traffic changes or failures. A network with TE capability can dynamically control traffic flows in order to prevent congestions and optimize the available resources [3].

Generally, optimization can be carried out at the traffic level and at the resource level using traffic engineering frameworks. At the traffic level, traffic oriented performance measures translate to the QoS requirements of any traffic [4]. The important traffic performance measures include delay, delay variation, packet loss, and throughput. At the resource level, network resources of interest include link bandwidth, the wireless channel, time, frequency, buffer space, and computational resources [4].

Over the years, several TE frameworks have been developed and successfully deployed in wire-line networks. Some examples of these frameworks are the Integrated Services (Intserv), Differentiated Services (Diffserv), and Multi-Protocol Label Switching (MPLS). However, these frameworks are not directly applicable in wireless networks. In addition, due to the stochastic nature of the wireless medium, the over-provisioning of network resources is not a realistic option in wireless networks. Efficient TE frameworks which can be used in wireless networks and the inter-working of wireless networks are still lacking. Even though the inter-working of wireless networks has several benefits, these benefits may not be maximized without effective traffic engineering. To maximize the benefits of inter-working, TE frameworks which are applicable to inter-working wireless networks have to be developed.

The development of TE frameworks for inter-working wireless networks is faced with a variety of challenges. These challenges can be attributed to the diversity in the characteristics of wireless access networks. Firstly, wireless access networks differ in their coverage ranges, data rates, underlying technologies, and operating carrier frequencies [2].

Secondly, some of the newly evolving wireless networks may be multi-service, multi-hop, and multi-channel in nature [5]. In a multi-service network, traffic such as data, voice, video, and multimedia co-exists. The traffic are generated by different applications and some of them place stringent QoS requirements on the network. Also, these traffic may contend for the simultaneous use of network resources. Since the resources of the network are limited, the challenge is how to provide fair QoS to these diverse traffic types traversing the inter-worked network while optimizing the network resources.

In multi-hop wireless networks, communication between two end nodes is achieved through a number of intermediate nodes. These intermediate nodes assist in relaying traffic from source to destination. A fundamental challenge in multi-hop networks is how to route traffic through optimal paths without violating their QoS demands and still ensure fair QoS while optimizing network resources.

In a multi-channel network, nodes are equipped to transmit traffic over multiple channels in order to increase the aggregate bandwidth of the network. The challenge posed by this characteristic is how to deal with the unpredictable nature of the wireless medium while optimizing the use of the channel to ensure fair QoS to the traffic.

Lastly, another major challenge for traffic engineering in inter-working wireless networks is the stochastic nature of the wireless transmission medium. For example, the network channel conditions and interference properties might change from time to time due to user mobility, wireless fading, changing weather conditions, or other external environmental factors [5]. Therefore, TE frameworks that can ensure reliable and fair QoS, and allocate resources efficiently to co-existing traffic traversing the unpredictable wireless medium are required for Inter-working wireless networks.

Few TE frameworks have been specifically designed to meet the attributes of wireless networks. In an attempt to extend the Diffserv for wireless networks [1] proposed a Wireless Diffserv. Other research works such as in [6] have also modified the DiffServ's approach for wireless networks.

This paper proposes a Multi-layer TE framework for inter-working wireless networks. Since next generation wireless networks will be multi-channel (MC), multi-hop (MH) and multi-service (MS) in nature, the proposed framework concentrates on the inter-working of these types of wireless access networks. The next section discusses the motivation for a multi-layer TE framework.

III. NEED FOR MULTILAYER TE FRAMEWORK IN INTERWORKING WIRELESS NETWORKS

Traffic Engineering (TE) in wireless access networks that are inter-worked is influenced by several parameters. Some of these parameters are linked to and controlled by the resources within the network. Consequently, such parameters need to be optimized for the network to properly dimension resources while provisioning fair QoS. However, these parameters (metrics) exist on different layers of the network stack within the network. For that reason, a multilayer solution needs to be explored in order to ensure efficient traffic engineering in inter-working wireless networks. In addition, each layer in the network contributes to the overall QoS experienced by a network-user. In view of that, a multi-layer approach will allow the metrics associated with QoS to be jointly controlled and be in synergy.

So far, there has been no TE framework which captures metrics that affects QoS from various layers in the network. This paper provides the concepts of a Multi-layer TE framework for inter-working wireless networks. The primary network stack layers of concern are the physical (PHY), MAC and network layers. The proposed framework captures the metrics (across these three layers) required to ensure reliable traffic engineering for user traffic.

Given that in a MS-MH-MC inter-working wireless network, some of the PHY, MAC and Network layer metrics influence each other and collectively affect the provisioning of reliable QoS, these metrics need to be jointly controlled. Some metrics affecting the provisioning of reliable QoS in wireless networks include the Bit Error Rate (BER), Signal to Noise and Interference Ratio (SNIR), channel delay spread, medium access delay (latency), throughput, delay, jitter, loss, blocking probability, and dropping probability. If a strong relationship can be established between these metrics, then using this relationship to determine a probabilistic bound on traffic QoS requirements, the Multilayer TE framework can:

- Ensure an optimal and reliable QoS to traffic.
- Fairly dimension resources to traffic contending for the wireless network resources.
- Ensure an optimization of these wireless network resources and thereby optimize the performance of the Inter-working Wireless Network.

IV. PROPOSED TRAFFIC ENGINEERING (TE) FRAMEWORK AND MODEL OF THE INTER-WORKING WIRELESS NETWORKS

A. *Proposed Multi-layer Traffic Engineering framework*

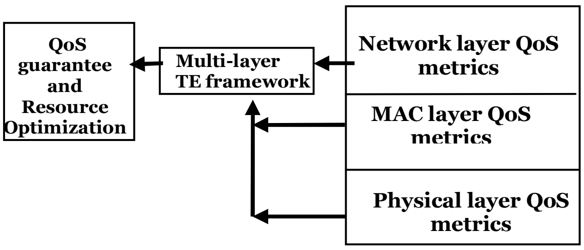

Figure 1. Model of Multi-layer Traffic Engineering Framework.

The proposed multi-layer TE framework in Fig. 1 jointly controls the physical layer, the MAC layer and the network-layer QoS metrics. It makes decisions in a manner that optimizes network's resources and guarantees traffic QoS.

On the physical layer, QoS may be defined in-terms of the BER or the Packet Error Rate (PER). Other metrics that contributes to the value of the BER include the channel delay spread and the SNIR.

The MAC layer protocols make decisions on how competing nodes may access the shared medium, i.e. the radio channel. These protocols ensure that no two nodes interfere with each other's transmissions. The performance metrics associated with this layer are access delay (latency), throughput, and fairness.

On the network layer, the QoS requirements of traffic are translated to QoS metrics, which are guaranteed by the protocols at this layer. Some of these QoS metrics are delay, jitter, loss and throughput. Since wireless links are prone to random errors due to channel impairment, the services they provide are stochastic in nature. Consequently, wireless networks can be considered as stochastic servers [8]. In addition the input traffic to these networks are stochastic in nature. Therefore, the proposed framework uses the stochastic Network Calculus (NetCal) methods to ensure stochastic bounds on traffic QoS requirement, within inter-working wireless networks. The basics of network calculus and stochastic network calculus are provided in [7] and [8].

In general, the stochastic NetCal concept provides bounds on backlog, delay, and burstiness, from the description of traffic arrival and the service given to traffic within the network. Fundamentally, it involves the application of the min-plus algebra to provide methods for computing performance bounds based on arrival curves and service curves. The purpose of arrival curves is to place a constraint on traffic's arrival process. These constraints are necessary in order to ensure service guarantees [9]. A service curve defined with stochastic NetCal allows the calculation of stochastic performance bounds for traffic's end-to-end QoS guarantees.

Stochastic NetCal has been shown in [8] to be an effective tool for analyzing end-to-end stochastic QoS performance for a traffic flow over a network. It is also useful for admission control and network dimensioning. It can be used to determine the amount of network resources needed for a traffic flow to meet its stochastic end-to-end QoS requirements [8].

Usually, in stochastic NetCal, the input and output traffic in a network are defined as two stochastic processes which are the cumulative arrival process: $A = A(t)$ for all $t \geq 0$ and the departure process: $D = D(t)$ for all $t \geq 0$ [10]. If ε is defined as the probability bound, then, the function $WN^{\varepsilon}(t)$ is an effective stochastic service curve for an arrival process A if equation 1 is satisfied for all $t \geq 0$ [10].

$$Pr\{D(t) \geq A \otimes WN^{\varepsilon}(t)\} \geq 1-\varepsilon \quad \forall t \geq 0 \qquad (1)$$

$WN^{\varepsilon}(t)$ is a non-negative and non-decreasing function, while $\otimes$ is a min-plus convolution operator. For illustration purpose, the convolution of two functions WN_1 and WN_2 under the min-plus algebra is defined in [8] as:

$$(WN_1 \otimes WN_2)(t) = \inf_{0 \leq s \leq t} \{WN_1(t-s) + WN_2(s)\} \qquad (2)$$

In this research, the probability bound of the service curve for the proposed Multi-layer TE framework is determined by the relationship between the QoS metrics of the three layers as shown in Fig. 1.

The framework determines a probabilistic bound, which optimizes available network resources. It then obtains an optimal network service curve with the probability bound, where optimal means that each traffic flow receives the required QoS with the least possible consumption of resources.

In general, the framework ensures optimal stochastic QoS bounds for traffic in MC-MH-MS inter-working wireless networks. It fairly dimensions network resources while optimizing the performance of the resulting inter-worked wireless networks. It takes the stochastic nature of the wireless medium and its effect on QoS provisioning into consideration in achieving these goals.

B. *Model of the inter-working wireless Networks*

Basically, if a wireless network (WN) can be modeled as a server providing service to traffic as shown in Fig. 2 and several of these wireless networks (servers) are inter-worked as in Fig. 3, then Fig. 4 describes the overall service offered to any traffic traversing the resulting inter-working wireless network.

For example if $WN_1, WN_2, \ldots WN_H$ in Fig. 3 represents the stochastic services curves provided by each of the wireless networks that are inter-working, then the service given to traffic flow f traversing the resulting Inter-worked wireless network is represented by equation 3.

$$WN_{net} = WN_1 \otimes WN_2 \otimes \ldots\ldots\ldots\ldots \otimes WN_H \qquad (3)$$

WN_{net} is the concatenation of the services curves provided by each of the wireless networks. It describes the service curve provided by the resulting inter-worked network.

Fig. 2. A wireless network as a server.

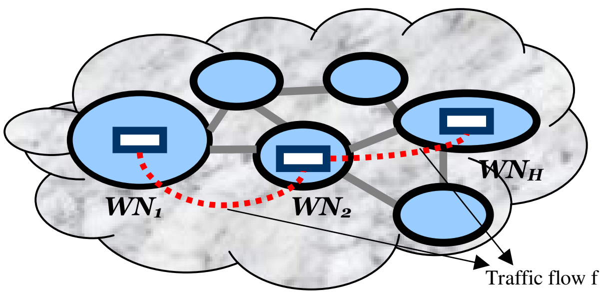

Fig. 3. Inter-working wireless networks

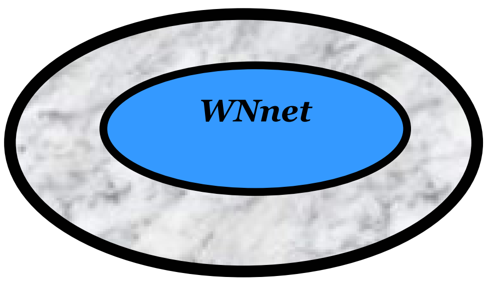

Fig. 4. Resulting Inter-worked networks.

The inter-working wireless network's service curve is obtained from the min-plus convolution of all the wireless networks' service curves.

V. CONCLUSION

With a focus on inter-working wireless networks, this research shows that multi-layer traffic engineering is needed. Existing TE framework such as the differentiated service and integrated services are not directly applicable to wireless networks. Therefore, applicable frameworks need to be developed for traffic engineering in wireless networks. The proposed multi-layer framework is a framework based on stochastic network calculus. The framework ensures the provisioning of reliable end-to-end QoS to traffic traversing the inter-worked wireless network. It also optimizes and fairly dimensions network resources among traffic without violating their QoS requirements. The generic framework can be applied to any set of inter-worked wireless networks.

REFERENCES

[1] H.Jiang, W. Zhuang, X. Shen, A. Abdrabou, P. Wang, "Differentiated Services for Wireless Mesh backbone", IEEE Communications Magazine, Vol. 44, no 7,pp. 113-119, July 2006.

[2] H.A. Chan, "Overview of wireless networks standards and their implementation issues", Tutorial 12th International Conference on telecommunications, May 3-5, 2005.

[3] R. Sabella and P. Iovanna, "Traffic Engineering in next generation multi-layer networks based on the GMPLS paradigm" Technical report, Ericsson Lab Italy – Via Anagnina 203, 00040 Roma (Italy).

[4] D. Awduche, A. Chiu, A. Elwalid, I. Widjaja, X. Xiao, "Overview and Principles of Internet Traffic Engineering", RFC 3272, May 2002.

[5] L. Georgiadis, M. J.Neely, and L. Tassiulas, "Resource Allocation and Cross-Layer Control in Wireless Networks" Foundations and Trends® in Networking, Vol. 1, No 1, pp. 1-144, ISBN: 1-933019-26-3, Now Publishers, 2006

[6] T. Janevski, "QoS framework for wireless IP networks", Proc. 6th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Service TELSIKS 2003, Oct 1-3. 2003. vol. 1, pp: 112 – 115.

[7] J.-Y. Le Boudec, P. Thiran, Network Calculus: A Theory of Deterministic Queuing Systems for the Internet, Springer-Verlag, LNCS 2050 Version, May 10, 2004. Available on: http://ica1www.epfl.ch/PS files/NetCal.htm.

[8] Y.Liu ,C-K. Tham , and Y. Jiang, "A calculus for stochastic QoS analysis", Elsevier Performance Evaluation Journal, vol. 64,pp 547-572, 2007.

[9] K.Pandit, J.Schmitt, C.Kirchner and R.Steinmetz, "A Transform for Network Calculus and its Application to Multimedia Networking", Proc. 13th annual Multimedia Computing and Networking (MMCN'06), Jan 18th-19th 2006, San Jose, California..

[10] F. Ciucu, A. Burchard, and J¨org Liebeherr, "A Network Service Curve Approach for the Stochastic Analysis of Networks", Proc. *SIGMETRICS'05,* June 6–10, 2005, Banff, Alberta, Canada.

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