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Traffic Scheduling Algorithm for Wireless Networks Using QoS Provisioning Framework

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Abstract

In this paper, a new Quality of Service (QoS) provisioning scheme based on centralized scheduling is proposed for mesh mode operation. The scheme is developed from the QoS mechanism of Point to Multi-Point (PMP) mode specified in 802.16 standards. A scheduling algorithm with the concept of Urgency Index is proposed for efficient bandwidth resource usage. The proposed QoS framework is implemented into simulation model to assess the effectiveness. Simulation result shows excellent QoS performance. The delay and throughput statistics obtained through simulation shows the proposed scheduler is more responsive to traffic load changes and makes efficient use of bandwidth resources. The main contribution of this work is the QoS provisioning framework in mesh mode, which fully considers the network capacity in a mesh network scenario and employs the specially designed cross-service-class Urgency Index based scheduling algorithm.

Keywords: Link scheduling, Wireless Mesh Networks, Quality of Service (QoS)

INTRODUCTION

The expeditious growths in customer impose for fast wireless connection to the Internet and VoIP services has driven the advancement of new broadband access technologies. WiMAX is one such broadband access technology developed aiming at providing broadband wireless access in Metropolitan Area Network (MAN). The WiMAX has been assigned with the IEEE 802.16 standards. A typical WiMAX network consists of one Base Station (BS) and multiple Subscriber Station (SS). The SS is connected to the external network through BS, so each BS act as a gateway for SS to foreign network. The SS act as an Access Point (AP) that ensemble the traffic from various end users [1]. In WiMAX, the PMP mode is the default mode of operation in which each SS communicates directly with the BS, which requires SSs to be one hop of range from BS and should be and also in light of sight (LOS). In Mesh mode, the SS also communicates with BS indirectly through other SSs via multi-hop indirect links. It could be seen that with Mesh topology, the network coverage is effectively extended and the capacity for non-LOS environments could be enhanced. Besides, in case of link failures or node failures, Mesh networks could have better reliability and availability.

The WiMAX standard supports four types of traffic services for QoS support. For the PMP mode, the standards also provide a general traffic scheduling scheme, including request and grant message definitions, frame structure, unicast and multicast message transmissions, and contention based requesting mechanisms [2]. A major challenge in wireless network is the ability to obtain higher throughput by means of link scheduling. Link scheduling refers to the selection of a group of links for simultaneous transmission [3].

Wireless mesh network based on WiMAX in which, wireless coverage problem associated with remote localities were user density is low and propagation problems due to intermittent terrain and large tree density are proposed by Hincapie et al. [4]. Wang et al. [5] focuses on WiMax mesh network for application in intelligent transportation systems. Scheduling algorithm with dynamic programming approach (SADP) for WiMAX mesh network is proposed by Chang et al. [6]. In this approach spatial reuse opportunities were exploited to maximize the network throughput of each SSs. A reservation based distributed scheduling approach was proposed by Vejarano and McNair [7], which allows links to transmit in any future frame by frame reservation. QoS issues in Mesh mode distributed scheduling have been proposed by Zhang et al. [8]. Cao et al. studied [9] the throughput enhancing techniques, together with a new notion of fairness of Mesh networks. A downlink scheduling for providing QoS guarantees in WiMax was proposed by Wu et al. [10] in which priority assignment and resource allocation was considered. A metaheuristic particle swarm optimization algorithm was proposed by Dosciatti et al. [11] to calculate the time frame duration and thereby guarantying the QoS. In mesh mode, QoS is attained in a message by message basis. How to provide QoS in Mesh mode is still an issue to be solved. The current solutions haven't done detailed inter-service scheduling analysis and simulation. This leaves wide space for researchers to propose various QoS schemes and traffic scheduling algorithms.

In this paper, a new QoS provisioning scheme based on centralized scheduling is proposed for mesh mode operation. The scheme is developed from the QoS mechanism of PMP mode specified in 802.16 standards. A scheduling algorithm with the concept of Urgency Index is proposed for efficient bandwidth resource usage. At the same time, the concept of spatial reuse in a relay-capable network is thoroughly investigated to achieve the maximum throughput within a mesh network. The proposed QoS framework is implemented into simulation model to assess the effectiveness. Simulation result shows excellent QoS performance. Comparison is done for the delay and throughput statistics with previous works, it shows the proposed scheduler is more responsive to traffic load changes and makes efficient use of bandwidth resources.

The rest of the paper is organized as follows. Section 2 does provide the system model of the problem. Section 3 describes the traffic bandwidth allocation algorithm. The data traffic scheduler algorithm is discussed in Section 4. Simulations are compared and discussed in section 5. Finally, Section 6 gives the concluding remarks.

SYSTEM MODEL

A typical WiMAX Mesh network scenario consisting of 1 BS and 12 SSs has been assumed for analyzing the proposed QoS scheme. In the assumed network, there are three branches to the BS (i.e. BS has three children nodes). The maximum hop number of SS nodes is four hops. SS nodes are labelled from 1 to 12, and the numbering starts from SS nodes that are nearest to BS. In the assumed topology, there are six nodes which serve as sponsor nodes to some SSs and relay traffic to and from BS. Quite a portion of SSs need to relay traffic or depend on the relay function of other nodes.

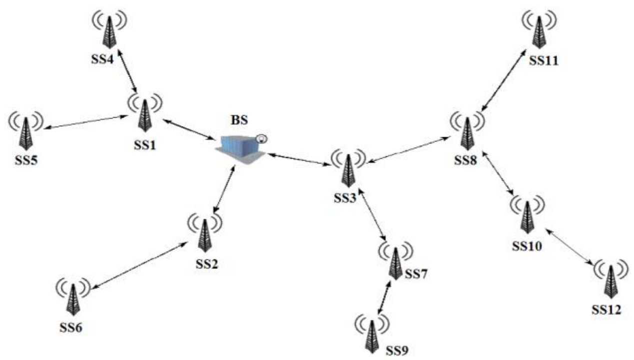

Figure 1: System model

The scheduling tree has been designed to be a 13×5 two-dimensional array. One dimension corresponds to the 12 SS nodes together with the BS, and the other dimension corresponds to important information of 1) number of hops from BS, 2) The parent node ID, 3) The critical node ID which is sponsoring the branch where this node resides, 4) The port number of the link to its parent node, 5) The port number of parent node where the link is leading to. With this scheduling tree array, each module has full information about the network and its own position in the topology with its module index number. The scheduler knows everything about the network topology and can perform all the algorithms introduced in previous sections readily. In the network, there is 1 Base Station and 12 Subscriber Station nodes. The first layer consists of three branches away from the BS and they are numbered from 1 to 12 with nodes nearer to the BS numbered first. The network has its furthest node (node 12) at a distance of 4 hops away from the BS. Six nodes are involved as relay nodes which are responsible for relaying traffic from their children nodes. The following network setup would be used for simulation as shown in the figure 1, corresponding discussion and results analysis. Corresponding to the network topology would be the scheduling tree description which is vital to the operation of the simulation. Each module would have to attain information about the network through the scheduling tree description. This takes form of a text file which consists of a 13-by-5 two-dimensional array and its contents are summarized below in Table 1.

The parameter selection closely follows the Standards physical layer specifications. For Mesh Networks, the modulation scheme is mandatory to be based on OFDM. Typically, the system uses frequency Channel Size of $20 - 28MHz$. In this work, the Channel Size of 25MHz is used as its also specified in Standards. Based on the system profile of 25MHz of frequency Channel Size, it can be derived there could be maximum of 529 OFDM symbols in one frame. For easy implementation of the system modeling the number of 512 OFDM symbols/frame was chosen. Based on QPSK scheme, one OFDM symbol is capable of carrying 48 bytes of data. The system Link Capacity can be further derived to be:

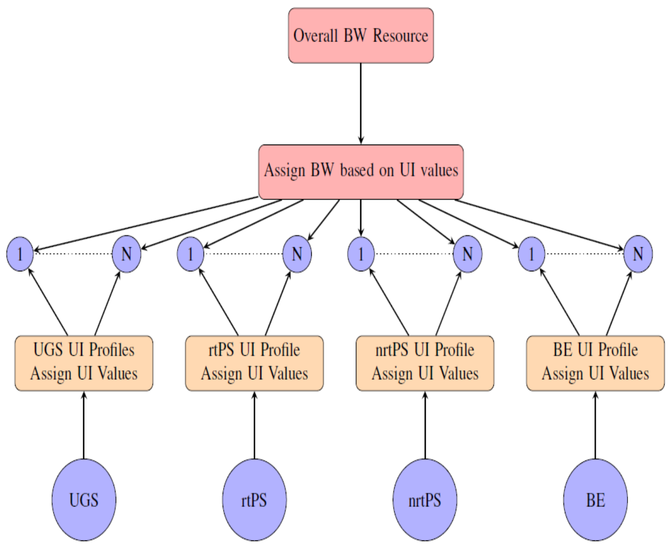

Figure.2 Bandwidth allocation to connections based on UI values

Table 1: Scheduling Tree Array Information

Node	0	1	2	3	4	5	6	7	8	9	10	11	12
Hop Count	0	1	1	1	2	2	2	2	2	3	3	3	4
Parent Node	0	0	0	0	1	1	2	3	3	7	8	8	10
Parent Port	0	2	0	2	0	0	0	0	0	0	0	0	0
Node Port	0	0	1	2	0	1	1	1	0	1	2	1	1
Critical Node	0	1	2	3	1	1	2	3	3	3	3	3	3

$$C_l = \frac{521\ OFDM \times 48 \times 8\ bits / OFDM}{5ms} \quad (1)$$

It should also be noted in Mesh Network traffic scheduling, traffic is allocated in terms of minislot. One minislot is one to a few OFDM symbols depending on the system profile. In standards, length of OFDM symbol is defined to be:

$$Ceil[(OFDM\ Symbols\ per\ \ frame - MSH - CTRL - LEN \times 7)/256] \quad (2)$$

It actually defines 256 minislots in one frame, and for the system profile adopted in this work, one minislot consists of 2 OFDM symbols. A scheduled traffic allocation consists of one or more minislots.

Traffic Model

Different service [3] types have different QoS requirements and traffic characteristics. Different connections of same service may possess different QoS parameters upon registration. Urgency Index (UI) values are used to differentiate the traffic allocation priority of all connections with accepted bandwidth requests, and bandwidth is allocated to connections from highest UI value to lowest. The scheme of bandwidth allocation based on UI values is illustrated in Fig. 2.

The scheme employs UI changing profiles to characterize the UI value of a specific connections traffic request. At connection registering process, each connection is characterized by a set of QoS parameters including their service type, mean traffic rate, and delay bound. The UI scheme aims to describe the urgency of requested traffic amount to its best extent on connection basis, rather than considering service type only or just based on earliest deadline first, which are traditional solutions for QoS.

A typical WiMAX Mesh network scenario consisting of 1 BS and 12 SSs has been assumed for analyzing the proposed QoS scheme. In the assumed network, there are three branches to the BS (i.e. BS has three children nodes). The maximum hop number of SS nodes is four hops. SS nodes are labelled from 1 to 12, and the numbering starts from SS nodes that are nearest to BS. In the assumed topology, there are six nodes which serve as sponsor nodes to some SSs and relay traffic to and from BS. Quite a portion of SSs need to relay traffic or depend on the relay function of other nodes.

The UGS connections are taken as conventional VoIP traffic without silence suppression. The traffic rate for each connection is 83Kbits/s with delay bound of 60ms. The UGS model is fixed packet size of 208 bytes, and fixed inter arrival time at the specified traffic rate. Extensive studies have been made on video streaming traffic in [12] to investigate the video traffic characteristics. Besides, real MPEG4 video streaming traffic packet size trace file can be obtained from [12] for network modelling purposes. Real traffic traces has some limitation as the mean traffic rate is fixed so it’s difficult to adjust the traffic percentage of rtPS traffic in the overall traffic load. Besides, if the network SSs only use traffic traces from a few particular videos, the traffic variation is low, and it does not generalize. The descriptive rtPS traffic model is adopted to overcome these two drawbacks. With reference to [12], the descriptive traffic model represents a traffic stream with fixed inter-arrival time and exponentially distributed packet size to simulate the burst nature of video streaming traffic. The BE traffic model represents a Poisson arrival process. Traffic inter-arrival time is exponentially distributed and the traffic packet size follows a typical HTTP traffic model as adopted in [13] is shown in the table II. The mean traffic rate is adjustable, and generates the following packet sizes (in bytes) and probabilities: (64, 0.6), (128, 0.06), (256, 0.04), (512, 0.02), (1024, 0.25), and (1518, 0.03).

Table 1: Traffic Model

Service Type	Traffic Model	Packet Size	Arrival Time	Delay Bound
UGS	VoIP	Fixed	Fixed	60ms
rtPS	MP4 Video	Exponential	Fixed	80ms
BE	Internet Traffic	As in [13]	Poisson	NA

Traffic Bandwidth Allocation Algorithm

As discussed in [9], the most efficient scheduler always try to make the traffic allocation on the Capacity Region boundaries (Pareto surface). The derivation showed the boundary condition is as following:

$$\sum_{k \in N(i)}^{N} \alpha_k \leq 1 \quad \forall\ i \in N \quad (3)$$

As proven with graph theory in [9], above condition is the sufficient condition for the traffic allocation vector to be schedulable and at the same time bounded within the Capacity Region. It says the summation of all the traffic going through links into a node and out of a node should be within the link capacity to guarantee the schedule is feasible. As the topic discussed here is uplink traffic between SSs and BS, by taking consideration of the relay requirements in a Mesh Network, it can be seen the nodes which are one hop away from BS have to relay traffic from the other SS nodes which are more hops away from BS. It can be easily deduced that if these one-hop SS nodes satisfy the condition in (5), all the other nodes that are multi-hops away also satisfy the condition and resulting in a schedulable allocation result. For a specific Mesh network configuration, the System Capacity is actually limited by a few nodes. By further analysis on this issue, these nodes actually include the BS and all the SS stations which are one hop away from BS. Let this set of critical nodes be denoted as Λ. This implication can greatly simplify the scheduling process as only processing work of a few nodes is necessary. The condition in 3 can be simplified to be

$$\sum_{k \in N(i)}^{N} \alpha_k \leq 1 \quad \forall\, i \in \Lambda \tag{4}$$

and Λ consists of 3-5 nodes

The Capacity Bandwidth Monitoring Array

The structure of a WiMAX Mesh topology is hierarchical, and for nodes which are a few hops away from BS the traffic has to be relayed a few times. This situation poses much difficulty in the calculation of total link usage to generate the traffic allocation result. For each link, in order to find the total traffic going through it the whole Scheduling Tree needs to be searched. Besides, any adjustments to the allocation result will cause the scheduler to go through the scheduling tree again to check whether it's within the system capacity. This problem is avoided by working on it the other way around. During the traffic allocation process, the traffic can be seen as released in small amounts each time. At the same time, its only necessary to monitor the status of the set of critical nodes. Let the amount of capacity left in each critical node be denoted as a changing vector M. Any amount of bandwidth allocated to some SS causes the vector set to change. As each critical node is parent node for a branch of Mesh SSs, any traffic allocation to this set of nodes all contributes to this specific parent node. In this way, only linear calculations are required on a status monitoring array with a short length of $|\Lambda|$. The problem of how much change some traffic allocation to a SS contributes to the change of M needs to be identified. By studying the topology and relay process, it can be seen the number of minislots K allocated to any SS node one hop from BS only causes the link between this node and BS to be activated for K/KC of time fraction. For rest of nodes, it should be noted that the traffic amount needs to be relayed to the hop-1 SS node first and then be re-transmitted to BS. In this way, the allocated traffic K minislots consume double of the link activation time discussed above. As a result, this problem can be easily handled by denoting the fact the set of Critical Nodes only consume the allocated bandwidth minislots in monitoring array, and the rest SS nodes cause 2×K allocated minislots towards its critical node for the branch where the SS resides in.

Data Traffic Scheduler Algorithm

This algorithm serves as the core function of bandwidth allocation at BS, and at the same time key solution to QoS provisioning in WiMAX Mesh network. Basically, the overall process is allocating bandwidth to active connections according to the set of UI values and at the same time monitoring the system resource usage array. The allocation process continues as long as the system is capable of servicing more bandwidth requirements and not all the requests have been fully serviced. Since the Scheduling Period is typically a few frame durations long, it is necessary to break the scheduling period into smaller time units in t_0 better utilize the UI changing curves, where t_0 the time unit in UI values scheme. In this way, BW within one Scheduling Period is divided into smaller sizes for allocation. It can be perceived as more sampling points are taken on a time varying curve. This results in accurate implementation of the proposed UI changing profiles for traffic allocation.

Scheduler complexity

The major steps performed by the scheduler is linear calculation and sorting of arrays. Linear calculations are just straight forward operations with formulas, and the complexity of calculations is O(1). The scheduler complexity comes from the step of sorting arrays. For the work in this report, Quick Sort is employed as the sorting algorithm. Since the scheduler complexity is from the sorting algorithm employed, the overall complexity for the proposed scheduler is O(Nlog2N). In a typical WiMAX system, the overall number of connections is limited. Besides, nowadays system hardware can easily handle algorithms of complexity level of O(Nlog2N), thus the scheduler efficiency is not a crucial issue and can yield satisfying results.

SIMULATION RESULTS

Extensive simulation has been done to evaluate the proposed scheduler performance. Simulation has been performed under different traffic load conditions to explore the delay, throughput, and the QoS features in terms of drop rate. Figure 3 compares the throughput statistics of each SS using two different scheduling algorithms. It can be seen QoS scheduler is performing well under the concept of fairness provisioning. The fairness constraint is applied to all SS nodes with no consideration whether extra bandwidth is still available. As a result, fairness among SS nodes is well maintained, but the overall system throughput achieved should be lower than proposed QoS scheduler.

The metric of system throughput is important to measure how efficient is the scheduler to utilize system bandwidth resources. As the traffic is normally characterized by the burst nature, its important the scheduler is capable of making use of system resource as much as possible, especially at situations of high traffic load. The throughput statistics are plotted in figure 4 for both the proposed QoS scheduler and reference scheduler as shown below. By inspecting the throughput curve, both schedulers give great performance in terms of throughput. At low traffic load region, all the traffic has been serviced with no loss. While it's more meaningful to look at the high traffic load region, the results are still impressive.

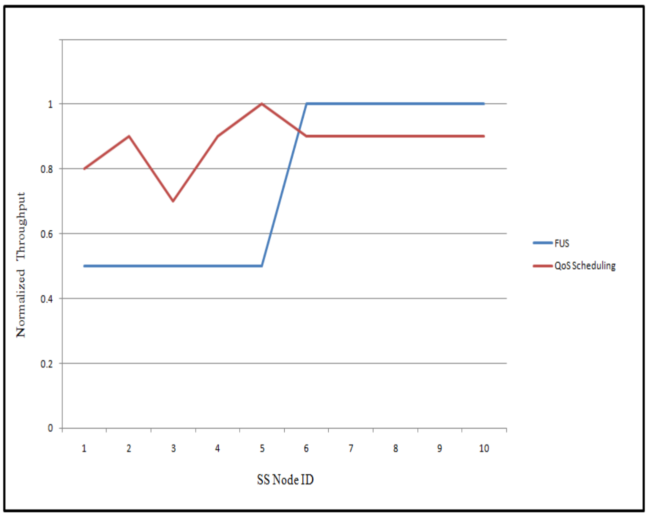

Figure 3: SS Throughput under different Scheduling Algorithms

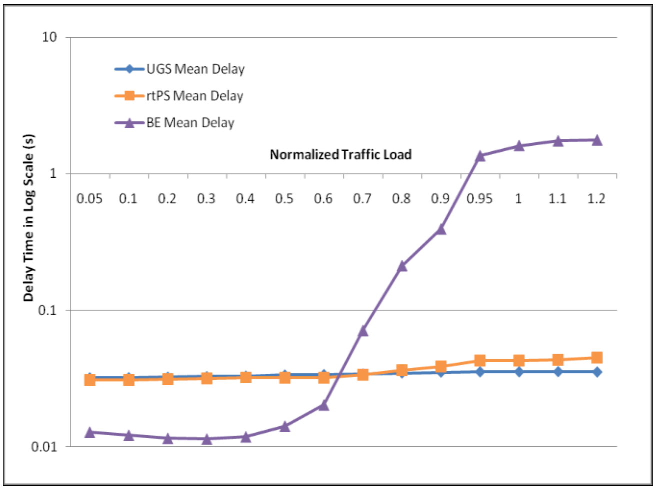

Figure 4: System throughput statistics plot against traffic load

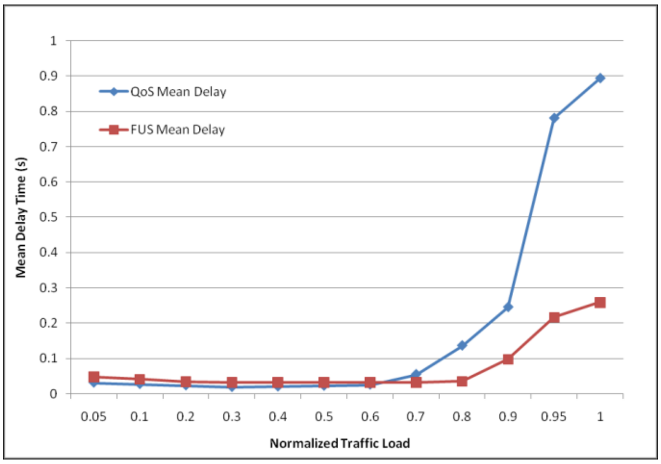

Figure 5: Delay statistics comparison between QoS scheduler and FUS scheduler

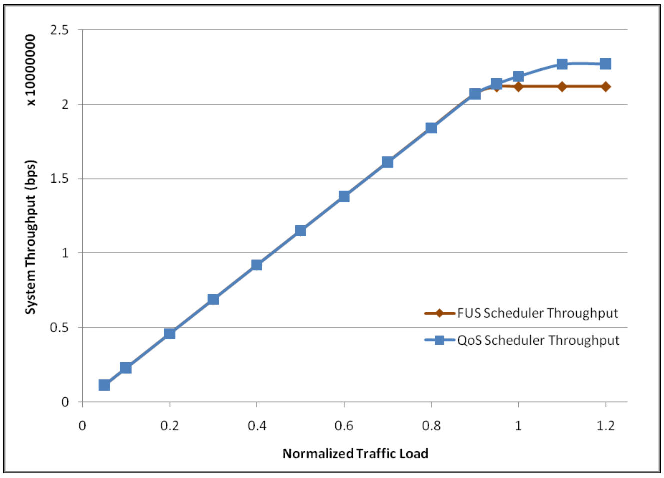

Figure 6: Delay Statistics plot for the three different Services

Delay statistics are also important to assess scheduler performance. The statistics of mean packets delay time for both referenced FUS scheduler and newly proposed QoS scheduler are plotted in figure 5 for comparison. The mean delay time statistics are collected at different traffic loads and detailed delay time plots are plotted. Based on the plot, it's observed when traffic load is below 0.6 of system capacity, newly proposed QoS scheduler performs slightly better than the referenced scheduler. Difference in this region is small as the delay time keeps being around a low value of 0.05s. When traffic load increases further, the discrepancy becomes large. The mean delay of proposed QoS scheduler scheme increases sharply while the referenced scheduler increases at a slower rate. The difference in mean delay statistics becomes larger as traffic load increases. It is necessary to look at detailed delay statistics of different service classes in the simulation. This will give a better idea about the QoS provisioning and effects on delay in the reasoning above.

The detailed delay statistics are plotted in the figure 6. The UGS & rtPS mean delay statistics almost kept constant throughout all traffic load conditions. This means the scheduler is effectively making best use of BW resources and providing QoS services effectively.

CONCLUSIONS

In this work, a novel scheduling scheme has been proposed to facilitate QoS provisioning in WiMAX Mesh mode operation. The UI profiles proposed best measures traffic demand urgencies among service flows. It breaks the traditional rigid priority assignment among service types specified in Standards, but comes out with waiting time related variable set to reflect allocation priority for each connection. In this scheme, the spatial reuse concept is also well implemented to achieve efficient use of bandwidth resources. Detail of the traffic relay scheduling was also studied and algorithm has been proposed to address this issue. With extensive simulation, the results show great performance of the proposed scheduling scheme. The core objective of QoS provisioning has been well achieved with outstanding low levels of packets drop rates. The total system throughput is close to maximum levels and the fairness among SSs has been well maintained. The analysis of delay statistics shows the traffic scheduler is intelligent and responsive to different traffic load conditions. All the objectives have been well achieved and the results obtained agree with theoretical analysis

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