Impact of Polling Strategy on Capacity of 802.11 Based Wireless Multimedia LANs

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Abstract

Wireless local area networks are a viable technology to support multimedia traffic. One of the prominent wireless local area network standards being adopted as a mature technology is the IEEE 802.11 standard. In wireless multimedia networks, mobile stations will be capable of generating a heterogeneous traffic mix and therefore it is crucial to devise an efficient bandwidth allocation scheme to satisfy the quality of service requirements of each traffic class. In this paper we present a distributed fair queuing scheme which is compatible with the 802.11 standard and can manage bandwidth allocation for delay sensitive traffic. The performance of the proposed scheme is evaluated by simulation, showing that a distributed version of deficit round robin outperforms the standard round robin service discipline from a capacity viewpoint.

1. Introduction

There is an increasing demand for wireless multimedia networks due to the attractiveness of providing network services to communicate using any type of media without any geographical restrictions. Therefore next generation wireless networks are expected to support multimedia services with guaranteed Quality of Service (QoS) for diverse traffic types (video, audio, and data).

Wireless Local Area Network (WLAN) has developed into a viable technology to support multimedia traffic. The IEEE 802.11[16] standard is being adopted by manufacturers and accepted by users as a mature WLAN technology. In this paper we explore the impact of a distributed fair queuing (FQ) strategy to allocate the bandwidth among stations in a WLAN to carry delay sensitive data traffic. In our simulation we used the IEEE 802.11 based wireless network with a heterogeneous traffic mix to evaluate the performance of proposed distributed FQ scheme.

The MAC protocol defined in the 802.11 standard uses a polling scheme to distribute the channel access permission among contending stations wishing to transmit delay sensitive data. However the standard does not define the method of managing the polling list. In this paper we will investigate the impact of polling schemes on the 802.11 based wireless network with voice, video and data traffic.

When the stations wish to transmit multimedia traffic with varying bandwidth requirements, it is important to allocate the resources (bandwidth) as fairly as possible. On the downlink the centralized coordinator which controls the contention free access can use standard FQ algorithms such as the Deficit Round Robin (DRR) algorithm described in [13]. Allocation of bandwidth (by being polled) for uplink traffic having varying bandwidth requirements is more difficult as the details of the traffic awaiting transmission are decentralized.

In [4][14], the *round robin* scheme was used as the scheduling algorithm to manage the polling list. These studies were mainly focused on evaluating the performance of the contention free access control mechanism of the 802.11 WLAN in an integrated Voice/Data environment.

In this paper we propose a distributed FQ algorithm based on the DRR scheme [13]. We call our scheme Distributed Deficit Round Robin (DDRR). We evaluate the performance of our scheme and compare it with the standard round robin scheme in terms of capacity. In brief the question we are trying to answer is “How many voice and video connections can be accommodated in an 802.11 WLAN satisfying the imposed QoS requirements under different scheduling schemes?”

The remainder of this paper is organized as follows. In Section 2 we outline the 802.11 access control mechanisms. Section 3 reviews some different schemes proposed for polling list management. Section 4 provides the details of our proposed DDRR scheme. Section 5 describes the simulation model and the simulation results are presented in Section 6.

2. Description of 802.11 wireless local area network access protocols

There are two access modes, Distributed Coordination Function (DCF) and Point Coordination Function (PCF), in the medium access control (MAC) sublayer of the 802.11 WLAN standard. These access modes provide contention based and contention free access to the physical medium. A centralized access point (AP), which is analogous to the base station in a cellular communication network, controls contention free access to the physical medium. The physical medium transmission time is divided into cycles and each cycle is further divided into two time periods, which correspond to DCF and PCF access control mechanisms. This is illustrated in Figure 1. In this paper we will focus on the PCF access method.

The Point Coordinator (PC) which sits in the AP transmits a beacon frame to start a Contention Free (CF) transmission by announcing the forthcoming Contention Free Period (CFP) to all the other stations in a cell. This puts all the other stations in a hold state until the PC polls stations. Once a station is polled it is given the right to transmit a single frame while all the other stations are stood back. This is described in detail in [3][4][14][15][16].

The CFP Repetition interval (Figure 1) describes the rate at which the CF cycle occurs. As mentioned earlier this cycle time is partitioned into two segments. The length of the CF period is bounded by a maximum value CFP_Max_Duration. According to the standard if the PC sends a poll request and if the station being polled does not have any data to transmit, the station sends a CF-NULL frame back to the PC. The 802.11 MAC header consists of a very useful bit called the “More Data” field, which can be used to convey the queue status to the scheduler. That is, in each response sent back to the PC, a station must set the “more data” field if it has more packets to send or reset it otherwise. We use this field in the proposed DDRR scheme to take the decision whether to poll a station or not. The idea behind this is to reduce the chances of polling empty queues.

During the contention period stations having either voice or video frames to transmit will compete for the channel together with other asynchronous data stations to transmit Association or Re-association frames. We use the “CF Polling Request” bit of the Capability information field of the Association and the Re-association frames to admit a station to the polling list and to remove a station from the polling list dynamically.

3. Polling List Management

As we mentioned earlier the 802.11 standard uses a polling scheme to allocate the available channel capacity among awaiting connections to transport uplink traffic. In a multimedia environment we can expect a wide range of flow characteristics having a range of delay, reliability and bandwidth requirements imposed by each flow. For example both voice and video impose stringent delay requirements. However the bandwidth requirement of a video flow is higher than a voice flow and video packets will typically be larger than voice packets. Thus employing an efficient polling scheme to allocate the bandwidth among these flows while fulfilling the individual flow requirements is important.

The basic model of the polling system associated to uplink traffic in a WLAN typically consists of N distributed queues and a single server (base station). We can identify two classes of service disciplines proposed for the polling list management at the base station. That is the “limited service discipline” class and the “non-limited service discipline” class. The algorithms in the limited service discipline class serve the queues up to a certain limit specified in terms of number of bits or the service time each visit to the queue. Therefore this approach avoids blocking of the transmission channel by a particular flow for a long time. This feature is very important when the network carries traffic with stringent delay requirements. In contrast to limited service discipline algorithms the non-limited service discipline algorithms can suffer from unfairness due to the fact that the sources which generate lengthy packets at a higher rate can easily block the channel for some time. The polling schemes investigated in [1][2][8] for multiplexing heterogeneous traffic in WLAN, come under this non-limited service discipline class.

The Fair Queuing (FQ) service discipline [5] can be considered as a limited service discipline. The primary goal of FQ is to serve queues in proportion to some predetermined service share independent of the queuing load. Different FQ algorithms use different approaches to determine the service limit (service share) for each queue in each visit. The round robin service discipline gives all queues an equal share of bandwidth assuming that the average packet size over the duration of a flow is the same for all flows[11]. However such an assumption is invalid for multimedia networks carrying a heterogeneous mix of Voice/Data/Video packets.

Demers et al. [5] devised an algorithm for more general packet networks assuming a fluid-flow traffic model. Due to the limitations of implementing such a scheme in packet based data networks, they extended the algorithm by requiring the server to pick the packet for service from queues in the order that they would finish the service according to a simulated fluid-flow model. As the computational complexity associated with simulation of fluid-flow traffic model is high it is hard to implement this algorithm cheaply at high speeds. An improved algorithm called self-clock fair queuing (SCFQ) was proposed in [6] to reduce the computational complexity. In this scheme the timestamp of the arriving packet is computed based on the timestamp of the packet being currently serviced.

A simple algorithm without any timestamp computation, called Deficit Round Robin (DRR)[13], was proposed by Shreedhar et al. This scheme is a simple modification of the round robin service discipline. In the DRR scheme, each queue i waiting for service has a state variable called *deficit counter* (DC_i). If the length of the next packet in the queue i is less than the value of DC_i, then queue i is allowed to send out its packet. It is clear that the scheduler has *a priori* knowledge of the next packet in the queue as the queues are localized to the scheduler. After the transmission if there are no more packets in queue i, the corresponding state variable DC_i is reset to zero. If there are more packets waiting in queue i, DC_i is decremented by L_i, the length of the packet transmitted. After that the scheduler continues to check whether DC_i is still greater than the length of the next packet, if so, the above procedure is repeated. If the DC_i value is not sufficient to transmit the packet, then the scheduler moves to the next station in the list stopping service to queue i. At the start of subsequent rounds, DC_i is incremented by a specific service share (quantum). The quantum value is used to specify the limit that the queues will be serviced in each visit. Thus DC keeps track of deficits in each round.

In a centralized queuing system the scheduler has access to the complete state of the queues. However in wireless networks the uplink traffic flows are decentralized (localized to the MS rather than at the PC) and the scheduler does not have direct access to the state of these distributed queues. Therefore none of the above FQ schemes can be directly used to schedule the uplink traffic in wireless networks.

A distributed FQ algorithm was proposed in [9] based on the SCFQ algorithm. In this scheme each mobile station is expected to piggyback a timestamp for packet k onto the transmission of packet $k-1$. If the packet k has not arrived in the queue by the time of transmission of packet $k-1$, the server has to send a special poll called a “tag poll” enabling the remote station to inform its’ status. Further the central scheduler must transmit the timestamp of the packet in service to the mobile stations to generate the timestamp of arriving packets.

Two limited service disciplines called Fully Gated Limited (FGL) and non-uniform FGL polling schemes which can be used for managing distributed queuing systems were analyzed in[10]. In the FGL scheme, once the server polls the remote queues at the beginning of each cycle, they reserve as many as they need to empty their buffer, up to a certain service limit. The server then gives service to the queues in the order which they have been polled. An improved version of the FGL called non-uniform FGL scheme was proposed to reduce the bandwidth wastage due to polling empty queues. In non-uniform polling, the basic idea is to poll each station as frequently as its traffic requirements necessitate. It has been shown that non-uniform FGL scheme outperforms FGL as it saves bandwidth wastage due to polling empty queues.

The 802.11 MAC protocol does not support the use any of these schemes, as they need to piggyback additional information either at the beginning of each cycle or during the cycle at MAC level. Instead we propose a distributed form of the DRR scheme to schedule the uplink traffic flows which is described in Section 4.

4. Distributed Deficit Round Robin scheme

In the Distributed Deficit Round Robin (DDRR) scheme, each distributed queue that managed to get admitted into the polling list at the PC is assigned a state variable called the Deficit Counter (DC). It is worth mentioning that these DCs are entirely managed by the scheduler running at the PC and are available at the PC. If the value of the i^{th} deficit counter (DC_i) is positive then the scheduler allows i^{th} queue to send first packet from its priority buffer, if any. Note that in the DDRR scheme packet is transmitted first and then “paid off” for the consumed bandwidth, rather than saving enough credit prior to the packet transmission as in the DRR scheme. Once the transmission is completed DC_i is decremented by L_i, where L_i is the length of the transmitted packet. If DC_i is still positive the scheduler checks the “More Data” field extracted from the previous packet transmission. If the “More Data” field indicates that station has got more packets in its priority buffer the scheduler continues to poll the same station. If the “More Data” bit indicates that there are no packets waiting in the priority buffer then the scheduler moves to the next in the list even if the associated credit counter value is positive. After that the i^{th} uplink flow is not polled again until the next CF cycle. If DC_i is negative the scheduler does not send a poll request to the i^{th} queue and then the scheduler moves to the next entry in the polling list. The basic idea behind this approach is to keep the stations which have seized a large fraction of bandwidth in their previous transmissions away for a while giving the chance to other stations to send their uplink traffic. Pseudo code for the DDRR algorithm is given in the Appendix.

Figure 2 illustrates how the transmission of packets in the i^{th} queue is scheduled according to the DDRR scheme. In Figure 2, rectangles on the left side represents the length of the packets waiting at a mobile station for service after becoming associated with the PC and rectangles on the right side represent the corresponding deficit counter maintained by the PC. In the first round, the i^{th} queue transmits the first two frames in the queue. After that DC_i goes negative and the i^{th} queue is not granted permission to transmit during second round. By the third round i^{th} queue has “paid off” for the previous packets it transmitted and is allowed to continue its transmission in this round.

Usually a network carries traffic in both uplink and downlink directions. Therefore the scheduler operating at the centralized coordinator (PC) must schedule both uplink and downlink traffic as to distribute the bandwidth fairly among all the uplink and downlink traffic flows. In such an overall-scheduling scheme, if the scheduler can send poll requests to the stations integrated with downlink data packets, it is possible to reduce the transmission of header bits. This approach helps to increase the unified transmission efficiency. The IEEE 802.11 standard supports this by allowing the MAC layer to integrate several frames during the contention free transmission period.

All the stations that are admitted into the polling list are called pollable stations. However it is possible for the PC to receive a packet from the backbone network to a particular station while that station is not in the polling list. In other words it is possible for an active downlink flow to exist while the corresponding uplink flow is inactive. Therefore the scheduler will have to schedule uplink and downlink traffic flows either simultaneously or independently.

In this work we consider the scheduling of traffic in both uplink and downlink directions as the network under consideration implements full-duplex sessions. The key points of the complete scheduling algorithm are:

- The scheduler maintains two independent counters, one for the uplink traffic flow and one for the downlink traffic flow for each duplex session.
- The uplink deficit counter is valid only for the stations, which have joined the scheduling list using association or re-association frames.
- All the uplink traffic is scheduled according to the DDRR scheme described above.
- The downlink deficit counter is valid only for the downlink queues set up at the PC.
- All the downlink traffic is scheduled according to the DRR scheme[13].
- When downlink data is sent, the receiving station is simultaneously polled (if its uplink credit counter is positive). This reduces the overhead of a separate poll message.

5. Simulation Description

The DDRR and round robin scheduling schemes were tested with a mixture of real-time traffic (voice and video) and non real-time asynchronous traffic. Section 5.1 describes the traffic models used and Section 5.2 presents system parameters.

5.1 Traffic Models

Voice traffic: The voice source is modelled using an ON/OFF process as detailed in [7]. Here the voice source is modelled as a two state Markov chain with a “talking state” and a “silent state”. When the source is in the talking state it periodically generates fixed size voice packets. We selected the CF repetition period identical to the inter-arrival time of these periodic voice packets.

Video traffic: As a video traffic source we used the MPEG-I traffic traces available at the FTP site *ftp-info3.informatik.uni-wuerzburg.de/pub/MPEG/* [12]. A video traffic source generates frames at a constant rate over its active period. The length of the video frame can be very large compared to the maximum length of the Mac Protocol Data Unit (MPDU) defined in the standard. These packets are segmented into constant size packets and sent to the MAC layer as a packet burst.

Data traffic: The presence of asynchronous traffic in an 802.11 based network results in transmission during the contention based period. The transmissions during the contention period may delay the start time of CF cycles. Since this is common in most practical situations, we used asynchronous data terminals to generate asynchronous traffic. The data traffic is generated using multiple stations. Both packet length distribution and data frame inter arrival time distribution form a negative exponential distribution.

5.2 System parameters

We used the default figures as specified in the standard [16] for all the DCF and PCF related attributes, which are not specified here. Tables 1 to 3 show the important user specified parameters. The contention free repetition interval (20 ms) is partitioned into a 15 ms CF period and a 5 ms contention period. This partition size is sufficient to transmit a maximum size MPDU.

PHY medium capacity	10 Mbps
Number of Data stations	10
Mean Aggregate Asynchronous data load	1 Mbps
CFP repetition interval	20 ms
CFP_Max_Duration	15 ms

Table 1: MAC and PHY channel configuring attributes

Voice source rate	64 Kbps
Voice frame duration	20 ms
Maximum speech delay	35 ms
Mean ON state duration	1.0 sec.
Mean OFF state duration	1.35 sec.
Voice Quantum size	2208 bits

Table 2: Attributes of a voice source

Video source rate	25 frames/sec.
Average Video frame length	15599 bits
Video frame duration	40 ms
Maximum Video Delay	100 ms
Video Quantum size	16524 bits

Table 3: Attributes of a video source

6 Simulation Results

To examine the performance of the DDRR polling scheme with the 802.11 MAC protocol, the following simulation has been performed. We set up a single cell wireless network with three different types of terminals. These data, voice and video terminals generate a heterogeneous mix of traffic according to the traffic models described in Section 5.1. The number of data stations was fixed to 10 and these 10 data stations generate asynchronous data traffic at an aggregate rate of 1Mbps. We varied the number of voice and video terminals and measured the delay experienced by each voice and video frame. We then determined the number of voice and video stations that can be supported by a 10 Mbps 802.11 WLAN satisfying the following QoS measures.

- 99% of the voice packets must be transmitted with voice packet delay less than 35 ms
- 99% of the video packets must be transmitted with video packet delay less than 100 ms

The “packet delay” in either case refers to the access delay which is the sum the MAC delay and the queuing delay in the local queue. At the end of the simulation, the fraction of frames that have been delayed beyond the specified lifetime was calculated. Note that packets are not discarded from the network as they expire. All the packets are transmitted irrespective of whether they have expired or not. In our simulations we model the physical channel as an error free channel. Each simulation run simulates 80,000 CF cycles. We ignore the results of initial warm-up period of 5,000 cycles.

Figure 3 shows the number of voice and video sessions that can be supported by the network satisfying the specified QoS measures under the DDRR scheduling scheme and the standard round robin scheduling scheme. The term “session” refers to a full duplex connection in this context. This study confirms that the scheduling scheme we proposed in Section 4 (DDRR/DRR) performs better than the standard round robin scheme in terms of capacity for IEEE 802.11 based wireless networks with a heterogeneous traffic mix having varying bandwidth requirements and delay characteristics.

Figure 4 shows how overall delay sensitive throughput varies with increasing number of video sessions when the network is presented with a mixture of voice and video traffic subjected to the specified QoS measures. Note that the throughput is calculated as a fraction of effective bandwidth available for contention free transmission. This graph clearly shows that DRRR gives better throughput compared to the round robin scheme. An increasing throughput can be achieved with increasing video load for both cases. This is due to the fact that the delay requirement of the video traffic is less compared to the delay requirements of the voice traffic.

7 Conclusion

We have described a modification to the Deficit Round Robin (DRR) scheme, which is suitable for distributed queuing systems. We call this distributed fair queueing algorithm Distributed Deficit Round Robin (DDRR). We proposed a scheduling scheme based on DDRR/DRR, which can be implemented at the base station. The proposed scheme can be used with IEEE 802.11 MAC protocol based wireless local area network to control delay sensitive traffic transmission during the contention free period. It was shown that the proposed scheme outperforms standard round robin scheme for 802.11 based multimedia networks from a capacity viewpoint

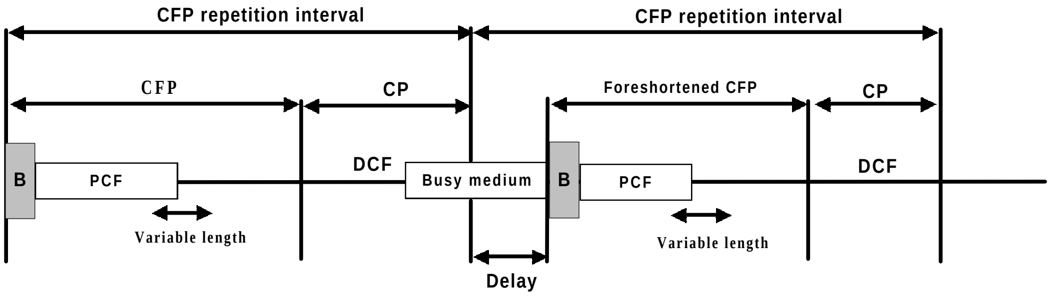

Figure 1: CFP/CP alternation within the Contention-Free repetition interval

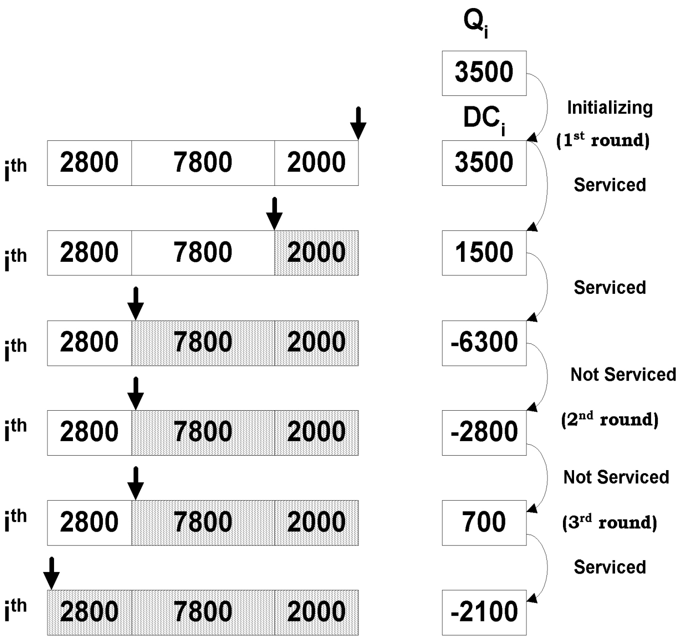

Figure 2: Distributed Deficit Round robin scheme

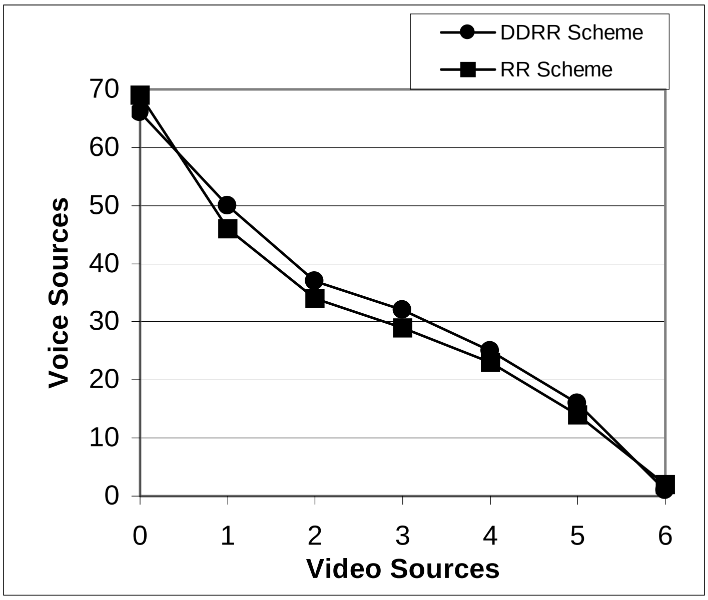

Figure 3: Voice sessions vs Video sessions that can be accommodated in an 802.11 based network under two scheduling disciplines

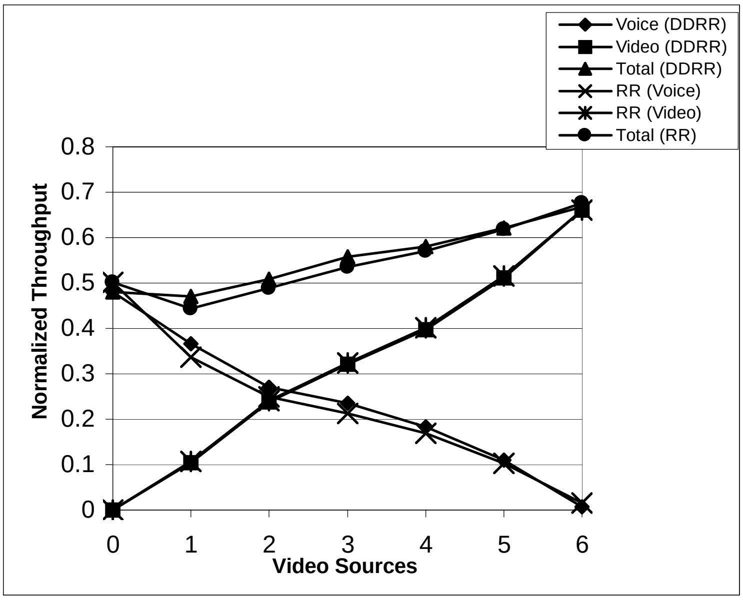

Figure 4: Throughput vs Video Sessions

Appendix

This appendix describes the distributed version of the deficit round robin scheme algorithm.

Algorithm:

Attaching module: On the arrival of an association or re-association request from terminal *i* in the wireless network or a packet from the backbone network, the corresponding deficit counter is initialized to DC_i = Quantum (type)$_i$, where type is either voice or video.

Polling module:

```
Set i to ActiveNode
WHILE ((SchedulingList is not empty) AND (CF
          remaining time < CF_MAX_Duration))
    $DC_i=DC_i+Q_i$;
    Set MoreDataBit;
    WHILE (($DC_i>0$) AND (MoreDataBit))
        Send a poll request to terminal i;
        Receive packet p;
        $DC_i=DC_i$- length of the packet p
        Read MoreDataBit from p;
    END-While
    i=i+1;
END-WHILE
```

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