An Assembly and Offset Assignment Scheme for Self-similar Traffic in Optical Burst Switched Networks

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***Abstract*— This paper proposes a Forward Equivalence Classification (FEC) assembly scheme to efficiently assemble self-similar traffic and a Pareto-offset assignment scheme for offset assignment. Two buffers, a packet buffer and a burst buffer, are implemented at the Label Edge Router (LER) to buffer traffic in the electronic domain. Burst assembly and offset assignment schemes are implemented in a complementary manner to improve QoS of an OBS network. We show that OBS network performance is directly related to burst assembly and offset assignment. We present simulation results of the assembly and offset assignment proposals using the ns2 network simulator. Our results show that combining the proposed FEC-Based assembly scheme and the Pareto-offset assignment scheme gives better network performance in terms of burst drop, resource contention, and delay.**

***Index Terms*— Self-Similarity, Forward Equivalence Classification, Burst Assembly**

I. INTRODUCTION

THE unprecedented and continual growth of Internet traffic in recent years is pushing current electronic switching technologies to their limits, whereas the all-optical switching technology is still in its early research stages. A viable alternative to all-optical switching is Optical Burst Switching (OBS), which was first proposed in [1] and has generated a lot of research interest. OBS uses all-optical switching for the payload data bursts and optical-electrical-optical switching for the burst header packet (BHP). The payload and header packet are separated by an offset time.

There are three main areas of study in OBS: burst assembly, scheduling of the assembled bursts, and routing of bursts to egress nodes. In this paper, we focus on burst assembly and setting of the offset times for the assembled traffic at the ingress node.

The increase in Internet traffic has led to important changes in traffic distribution that must be considered during assembly. Leland *et al.* in [2] and [3] showed that Internet traffic has indeed deviated from the traditional Poisson distribution to a distribution that is heavy tailed in nature. The heavy tailed distribution is said to exhibit Long Range Dependence (LRD). LRD characteristics imply that Internet traffic has an infinite variance, which in turn implies that the probability under the heavy tail of the distribution accumulates to a non-negligible probability. Modelling Internet traffic using the Poisson distribution, which exhibits Short Range Dependence (SRD) and therefore finite variance, has neglected a significant fraction of the probability distribution which resides in the 'tail'.

The Hurst parameter H, which measures the burstiness of traffic, relates to LRD of traffic with the equation,

$$H = (3-\alpha)/2, \text{ with } 0.5<H<1,\ 1<\alpha<2 , \qquad (1)$$

where α is the shape of the tail of LRD traffic. The burstiness of traffic increases as H and α tend to 1 and 2 respectively. Between 1 and 2, the shape parameter has a finite mean and an infinite variance, which is a characteristic of Internet traffic.

Studies on the impact of the burstiness of traffic on queuing models using heavy tailed distributions have shown that with increase in self-similarity, queue performance is significantly degraded. Results in [4] and [6] demonstrate how self-similarity is critical to traffic engineering. The self-similar characteristic must be taken into account during assembly of bursts to avoid excessive queuing delays.

The Pareto distribution is one of several heavy tailed distributions known and is simplest to implement in modelling self-similarity. Willinger et. al. in [5] has shown that aggregated streams of Pareto ON/OFF streams result in self-similar traffic. In [7] Qiao shows that the self-similarity of traffic does not reduce significantly after burst assembly. This is contrary to reports in [8] and [9], where self-similarity is reported to reduce significantly. However several studies have been published to support results in [7]. In this study we model assembled traffic as Pareto-like streams, in the form of bursts and offset times.

In our assembly scheme, we take delay tolerance of each individual packet to be the primary QoS parameter for packets being assembled. The assembly scheme assembles bursts without violating the delay tolerance of the packets. The scheme also ensures that the sent bursts are not too short, which would compromise the performance of the OBS network.

We aggregate streams of ON/OFF Pareto distributed periods to generate self-similar traffic. We assume wavelength conversion is available at every Label Switch Router (LSR) node in the core, and a Just Enough Time (JET) reservation scheme proposed in [1] is used. The Latest Available Unused Channel with Void Filling (LAUC-VF) scheduling scheme is used in our analysis. No electronic buffers at LSR nodes or Fibre Delay Lines (FDL) are used.

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We next highlight previous related works (Section II), then propose an FEC-based assembly and an offset assignment scheme (section III). We then discuss the results on the performance of the assembly and offset assignment schemes (section IV) and draw conclusions (section V) of the study.

II. PREVIOUS RELATED WORK

In this section we highlight some of the prior work in burst assembly and offset-based QoS schemes.

Burst assembly schemes are broadly classified into three major categories: Burstlength-based, Timer-based, and mixed timer/burstlength-based [1]. Recent research efforts have focused on assembly of bursts using schemes that support QoS.

In [9] a Composite Class Burst (CCB) assembly scheme that takes into account delay tolerance is proposed. CCB defines burst classes with respect to different assembly times after which a burst is transmitted. Assembly of bursts using CCB allows for different packets to be assembled in the same burst and is faster compared to assembling same packet types.

An *extra offset time* QoS scheme is proposed in [10] using FDLs and in [11] without using FDLs. The extra offset method in [12] considers two classes of traffic, real time and non-real time. It is shown that assigning longer offset times to real time applications significantly reduces their probabilities of blocking. However, [13] argued that assigning long offset times to high priority bursts results in prolonged end-to-end delays. This is true, though long offset times should be redefined and to limited to fall within the end-to-end delay tolerances of a given burst class.

In [14] a threshold assembly scheme is proposed instead to reduce delay, and contention is resolved using priority-based segmentation. Segmentation policies demand that each field of a burst has a specified length, and burst classes have fixed lengths. This method would result in long queues at the ingress nodes due to the slow generation and transmission of bursts. This scheme would not perform well especially with bursty traffic, just as SONET has failed with bursty traffic.

From previous works, offset-based schemes can be modified to cater for QoS in OBS networks by appropriately controlling long offset times to be within delay tolerance limits of a burst. Assembly schemes need to assemble bursty traffic and still guarantee end-to-end QoS of the assembled bursts.

III. PROPOSED QOS SCHEME

We propose an assembly algorithm that takes into account the effects of self-similarity to improve the performance of an OBS network.

In assembling bursts to cater for QoS, it is imperative that offset assignment be carried out as a complementary procedure to burst assembly. We propose a Forward Equivalence Classification (FEC-based) scheme that complements a Pareto-based offset scheme.

A. *FEC Packet Classification*

Each packet entering the packet buffer has QoS requirements independent of the other packets in the buffer. We use decision theory [15] to classify packets into an appropriate burst during assembly. The decision making is based on the fact that every class of traffic has a delay tolerance that allows for flexibility during packet routing, and on the assumption that no packet has a delay tolerance less than the amount of time it takes to route the packet through the OBS network using the shortest route to its destination.

We assume 4 classes of traffic: delay tolerance in the range of micro seconds (class 1), low milliseconds delays (class 2), high-end milliseconds delays (class 3) and background traffic with several seconds to minutes delay tolerances (class 4). We will model four different packet types referred to as packet type 1, packet type 2, packet type 3, and packet type 4. We then classify these packet types into four different Forward Equivalence Classifications (FEC) referred to as FEC A, FEC B, FEC C and FEC D shown in Table I, with FEC A giving priority to the least delay tolerant packets in the packet buffer and FEC D giving priority to the most delay tolerant traffic.

We use the symbol $\succ$ to indicate strict preference of one FEC to another and $\succ\sim$ to indicate relative preference.

TABLE I
FORWARD EQUIVALENCE CLASSIFICATION OF PACKETS WITH QOS

	FEC Preference
Packet type 1	$A \succ_1 B \succ_1 C \succ_1 D$
Packet type 2	$B \succ\sim_2 A \succ_2 C \succ_2 D$
Packet type 3	$C \succ\sim_3 B \succ\sim_3 A \succ_3 D$
Packet type 4	$D \succ\sim_4 C \succ\sim_4 B \succ\sim_4 A$

The decision maker is according to the packet type in this case. Table I shows that packet types 1 strictly prefer FEC A and will not accept other classification if FEC A is available. Should FEC A not be available, FEC B is chosen instead; and if FEC B is also not available, FEC C is chosen; with FEC D being the last choice. However, for packet types 2, preference is given to FEC B, but may also be given to FEC A. If FEC B and FEC A are not available, then preference is to FEC C and then FEC D. It should be noted that when a packet type of higher priority is assigned to a lower priority FEC, then pre-emption is more likely during assembly to prevent delay tolerance violation. From Table I, the proposed FEC scheme results in assembly of bursts that may have multiple packet types while guaranteeing the QoS for each individual packet.

Bursts in the core network after assembly are differentiated either as FEC 1, FEC 2, FEC 3, or FEC 4, with FEC 1 having the highest priority and FEC 4 having the lowest. This classification is the equivalent of packet classes before assembly. Bursts assembled from FEC A become FEC 1 bursts and likewise FEC B, FEC C and FEC D become FEC 2, FEC 3 and FEC 4 bursts respectively. By meeting the QoS demands for each of the packets, we do not compromise network performance. Therefore all bursts transmitted must have the minimum and maximum burst lengths. The decision as to which FEC a burst should take is continually made and updated as the burst is being assembled, and a final decision made when the burst has been fully assembled.

B. *Considerations for burst assembly*

We identify the following factors to be critical to the optimal performance of an OBS network: modelling OBS traffic, destination of the burst, burstiness of incoming traffic, delay tolerance restrictions of the received packets, and minimum and maximum burst length restrictions.

- Modelling OBS traffic

The difficulty of modelling self-similar traffic has led many researchers assume Poisson traffic for burstification. In this section we give an abstract mathematical analysis of self-similar traffic. From [4] it is shown that assembled Internet traffic smoothens a little, but self-similarity persists and LRD of the assembled traffic still exists. A comparison between Optical Packet Switching (OPS) and OBS is made, with self-similar traffic as the incoming traffic at the ingress node. The R/S distributions show that the distributions of the assembled bursts compared to that of OPS deviate only slightly, such that the assembled traffic, though smoother, is still significantly bursty and exhibits self-similarity.

One challenge in OBS is in the mathematical treatment of the OBS-traffic. Poisson based queue schemes use the assumption; given that input traffic is Poisson distributed, with an optimal queuing scheme, the output distribution of the queue or queue network will also be Poisson distributed. This assumption has worked well over the years. We infer from the assumption made in Poisson based queues and propose that it is feasible to model OBS-traffic as ON/OFF periods. We use a similar argument; *given a Pareto distributed input to a queue, with an optimal queuing scheme the output traffic must be Pareto distributed*. We assume a Pareto input, since self-similar traffic can be modelled as Pareto aggregated streams. Pareto streams can in turn be modelled as ON/OFF periods, which can in turn be modelled as OBS traffic flows.

The burst period preceded by an offset period gives a natural correspondence to Pareto ON/OFF periods (Figure 1).

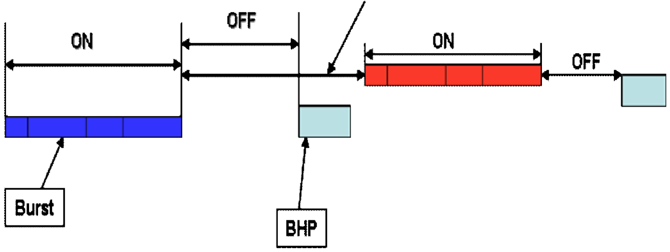

Figure 1. Proposed offset assignment scheme.

The ON periods in Pareto are modelled as the burst duration, while the OFF periods are modelled as the offset times. Modelling OBS core traffic in this manner allows for a per channel flow modelling in DWDM wavelengths. Figure 1 shows the overall proposed LER traffic set-up. Modelling OBS traffic as ON/OFF periods in DWDM conforms to the same distribution theory in Jackson queues.

C. *The burst queue*

In this section we develop several rules for the burst queue.

Rule 1: *After a BHP corresponding to a lower priority burst has been transmitted, the burst to be transmitted may not be pre-empted by a higher priority burst.*

The burst queue is serviced by the wavelengths available at the LER. We consider an LER with DWDM and wavelength conversion capabilities.

Service time S_t for the burst queue will include assignment of an offset time to a burst and the transmission time. The offset time will depend on a specified FEC, while the transmission time will depend on the duration of the burst. We avoid pre-emption during the transmission of BHPs and bursts since OBS is a one way protocol.

Instead of four events in previous schemes, there are three events that take place at the burst queue in this scheme, which reduces delay:

1. Assembled bursts with delay tolerance restrictions, each with a specific destination, arrive at the queue.
2. BHP packets are transmitted to set an offset for a burst in the queue.
3. The burst is then transmitted after the offset is set.

The choice as to which burst is transmitted from the queue depends on delay tolerance of a given burst assembly, the arrival rate of classes, and the required offset times which are used to determine the service times.

1) *Delay tolerance*

Rule 2: *If there is contention for a wavelength between a low priority and high priority burst, the burst with a shorter delay tolerance will be served before the burst with a longer delay tolerance.*

Unlike at the packet queue, we do not queue the bursts into four classes. Bursts are instead served depending on their delay tolerance. A burst with long delay tolerance such as an e-mail burst will be transmitted after voice traffic burst. Rule 2 avoids a strict First In First Out (FIFO) queuing routine and maintains QoS of bursts.

2) *Class arrival rates*

Rule 3: *The rate of arrival for any class into the burst buffer must not exceed the rate of burst transmission.*

At given instances, one traffic type may be more prevalent than other traffic types. If delay tolerance is the only factor used to transmit, then one burst type destined for a given destination or destinations may lead to an overflow of the buffer after a given period of time. To avoid buffer overflow due to one traffic type, the rate of transmission of the traffic type must be increased by a factor *alpha* while keeping that the throughput of the class less than one.

3) Required offset

> **Rule 4:** *More than one offset may be set in a given time slot to allow for void-filling.*

We define a timeslot as the time used to set an offset for a burst. Void-filling at the LER enables efficient use of the available wavelengths and minimizes delays in the queue. Consider three bursts in the queue. Let the assigned offset times be t_1, t_2 and t_3, for bursts with burst lengths b_1, b_2 and b_3 respectively.

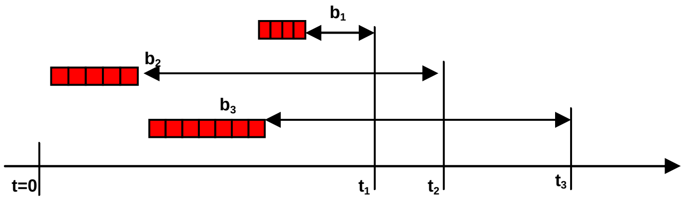

Figure 2. Use of offset times to minimize delays in the burst queue while increasing wavelength usage.

From Figure 2 it can be seen that burst length b_1 can be transmitted during the offset time of burst length b_3. The offset time of burst length b_2 can be set simultaneously with that of burst length b_3, but only if the burst can be transmitted after burst length b_3.

D. Distribution of exiting times

The distribution of the transmission times are dependent on the distribution of the burst lengths and offset times, if the offset times are random. Offset lengths are dependent on the destination of a burst and its delay tolerance and are independent of the burst lengths.

IV. SIMULATION RESULTS

We now present our simulation results and discuss their implications. The topology used for simulation is shown in Figure 3.

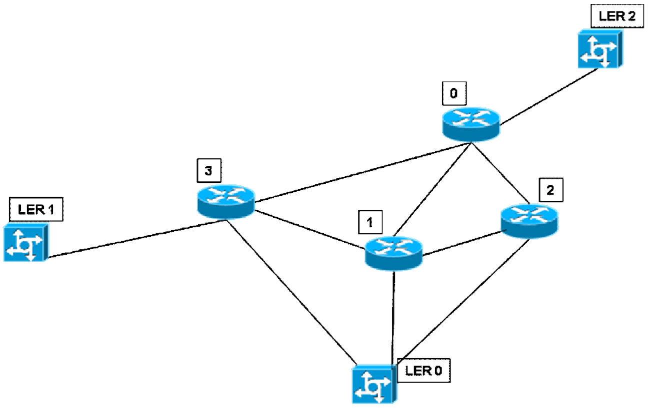

Figure 3. Topology used for simulations.

We use a finite queue network set-up to simulate performance of an OBS network using the proposed scheme. Previous assembly schemes and offset assignment schemes are contrasted on the queue network with the proposed FEC-based and Pareto-offset assignment schemes. In the results we show that traditional Poisson modelled traffic does not give a true indication of network performance or characteristics.

The simulation results highlight the following aspects:

1. The effect of traditional exponential traffic on an OBS network compared to self-similar traffic
2. Performance of the proposed FEC-based assembly scheme in comparison to the timer and mixed –timer-length based assembly schemes
3. The relation between packet queue management and burst loss in the core
4. Performance of the proposed FEC-based assembly and Pareto-offset assignment scheme in terms of delay of bursts, at the LER and burst drops.

A. The Proposed FEC-based assembly scheme

The proposed FEC-Based assembly scheme results in bursts with burst length distributions shown in Figure 4. Figure 4 shows a sample of bursts of FEC-4, and FEC-1-3. We allow for bursts of FEC 4 to have burst lengths up to 5000 KB, and a minimum 4000 KB. This is because for FEC-4 bursts, delay is not a major constraint, and burst lengths of up to 5000 KB can be assembled without violating time delay constraints. It should be noted that though FEC-4 bursts are assembled using a constant length based scheme, their burst lengths vary. The variation in burst lengths is due to the design of the FEC-based assembly scheme, which dictates when the threshold of 4000 KB of FEC-4 packets is reached. There also exist, in the buffer FEC 1-3 packets, these packets are used to pad the burst with a maximum of 5000 KB in length. Pre-emption must therefore occur if padding of packets with FEC 1-3 is done to avoid delay tolerance violation.

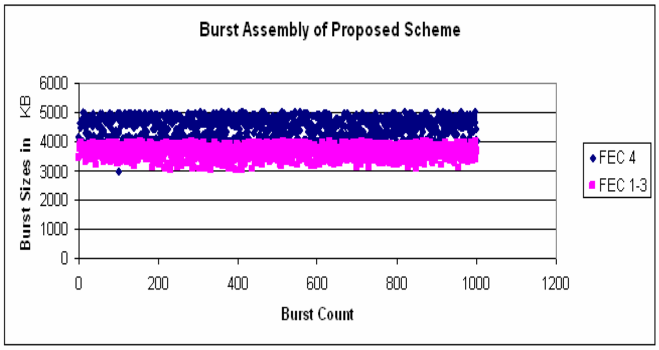

Figure 4. Distribution of assembled bursts using the proposed FEC-Based Assembly scheme.

The proposed FEC-based assembly scheme results in fewer bursts being dropped compared to length, timer, and mixed-timer length based schemes. This result is expected since bursts in the FEC-based scheme are on average longer due to the isolation of FEC-4.

We may compare bursts assembled with Mixed-Timer assembly (Figure 5) with bursts assembled with the proposed FEC-based scheme (Figure 4). Bursts from the FEC-Based scheme are generally longer than those from the Mixed-timer-Length based scheme. No FEC is used in Figure 5. Generally, the longer the bursts, the less probability number of bursts in the core for the same amount of input traffic, more efficient use of wavelengths and therefore less resource contention.

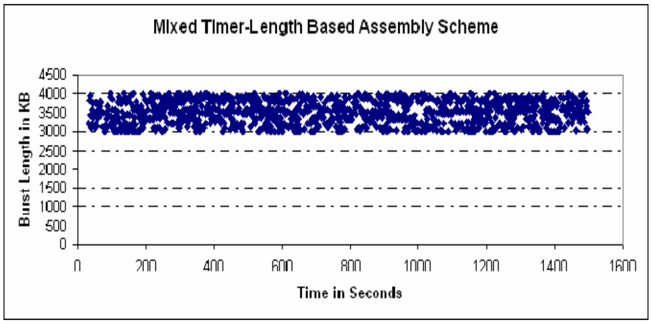

Figure 5. Burst lengths when a mixed-timer-length based scheme is used for assembly without FEC.

B. *Offset Assignment*

Figure 6 shows burst drops of the simulations with different offset assignment schemes. Const-Pareto represents constant offset assignment for self-similar traffic and const-exp represents constant offset assignment and exponential traffic respectively. The Pareto and Uniform bars in this figure show Pareto and uniform offset assignment for self-similar traffic. The burst drop percentage for exponential traffic clearly underestimates burst drops for real Internet traffic depicted here by aggregated Pareto distributions to give self-similar traffic.

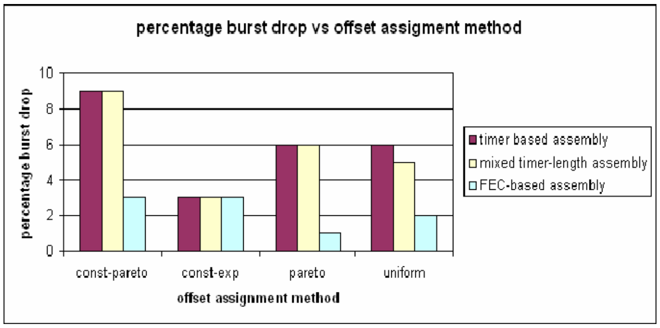

Figure 6. Summary of the performance of the proposed assembly and offset assignment schemes using the proposed queue management method.

Figure 6 also shows that assembly with the proposed scheme results in a lower percentage of burst drops compared to the timer and mixed-timer-length based assembly schemes. The timer-based and mixed timer based assembly schemes generally have the same performance for the traffic settings in these simulations. An important observation is that the combination of the proposed FEC-assembly scheme and the Pareto offset assignment results in the lowest number of burst drops.

C. *Buffer Delays*

It can be intuitively deduced that different methods of offset assignment have different effects on the delay at the ingress node. The different delays would depend on the distribution and lengths of the offset times. In Figure 7 and Figure 8, we show the effect of different offset assignment on two different burst assembly schemes. The aggregation of 35 connections for Pareto distributed traffic result in self-similar traffic.

Figure 7 shows delays incurred by bursts at the burst buffer using the timer-based assembly scheme. Figure 8 shows delays incurred by bursts at the burst buffer using the proposed FEC-based assembly scheme.

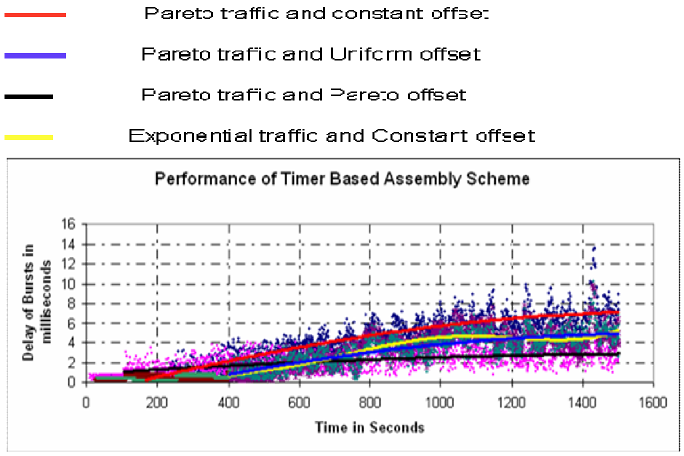

Figure7. How delay of assembled bursts varies at the LER when different offset assignment schemes are used on the timer-based assembly scheme.

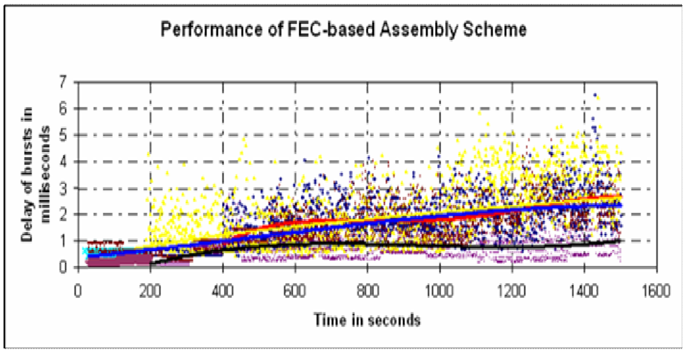

Figure 8. How delay of assembled bursts varies at the LER when different offset assignment schemes are used on the proposed FEC-Assembly scheme

Figure 7 shows that for self-similar and constant offset assignment, bursts will incur more delay compared to exponential traffic with constant offset assignment. The reason for this is because exponential traffic underestimates the burstiness of the traffic. This result agrees with previous work in literature. When offset assignment is made random rather than constant, for self-similar traffic, delay of bursts in the burst buffer decreases. From Figure 8, delays by uniform offset assignment are lower than delays for the same self-similar traffic with constant offset assignment. However, delays are further reduced by using the proposed Pareto offset assignment scheme. We account the different in delay to the more random variance of the Pareto distribution, compared to the uniform distribution.

In Figure 8, we instead use the proposed FEC-based assembly scheme. Overall delay of bursts is lower than that of the timer based assembly scheme. However, delay by constant offset and uniform offset assignments are not as different in this case, as is for the timer based assembly scheme. Notable though, is the lower delay of bursts when offset assignment is done using the Pareto offset assignment.

V. CONCLUSIONS

From the simulation results in this study, we have shown the following:

1. Self-similar traffic has a significant effect on delays incurred at the LER
2. Self-similar traffic cannot justifiably be estimated to be close to Poisson modelled traffic
3. Assembled OBS traffic can be modelled as ON/OFF periods with On periods being the burst lengths and OFF periods the offset periods
4. The randomness of offset assignment has a direct relation to contention of resources at LSRs
5. The proposed FEC assembly scheme results in shorter packet queue length and longer burst lengths results in less contention of resources

We conclude that there are three interdependent factors that affect OBS network performance: Packet queue management; method used to assemble the packets; and offset assignment scheme used.

The successful implementation of an efficient OBS network will have great benefits to both civilian and the military. OBS is especially suited for time critical large amounts of data that need to be transmitted with high efficiency.

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