Effective Frame Switching using a Network Traffic Oscillator

Y. K. Mo, M. S. Leeson and R. J. Green

Abstract—**this paper discusses the importance of effective frame switching to further improve the accessibility of service in a real time communication system. Frame switching is performed by connecting frames to their destination. When the network is busy, frame response times fluctuate. Dynamic frame traffic oscillation allows the frame workload to be more manageable for network link capacity assignment. This concept, which we term *Critical Networking* reduces network resource wastage and removes application network frame delay by carefully planning the type of frame transmission and the available network resource. The frame traffic organization is handled by a network traffic oscillator (NTO). Deterministic time response in frame transmission can be achieved by working with an effective frame transmission plan using the NTO and Critical Networking. Both concepts when combined remove the need to assign arbitrary priority numbers in frames, overheads for consecutive application transmissions and additional overhead for every frame switching instructions. The concept is illustrated using a simulation of real-time traffic in an airfield scenario.**

Index Terms—**Deterministic Ethernet, Critical Networking, Network Traffic Oscillator, Time Critical Network.**

I. Introduction

The Ethernet system has a strict frame structure according to its standard [1]; it has a minimum and maximum frame size and a frame overhead for every frame to handle network transmission instruction. Its transmission characteristics are however random. This frame transmission randomness is caused by other external factors such as network switching arrangements [2] and application transmission requirements. A unified platform in a coherent transmission window, spanning switching and application transmission promotes punctuality in frame transmission, and ultimate reduces frames lost from timeouts. This is difficult to achieve as it involves network structure planning in all OSI layers [3]. This problem is a common issue amongst real-time communication networks. One contemporary example is a car area network [4], where the link is busy and frames do not necessary arrive in sequence. Priority frame switching has been introduced to allow important frames to be transmitted first but this only temporarily reduces some of the important frame delays on a selection of applications. Time Triggered Ethernet (TTE) on the other hand, is an architecture protocol designed for critical time window transmission [5]. This protocol primarily focuses on maintaining a target time transmission window by forcing frames to be delivered within a slotted window. This is useful in ad-hoc point to point communications, where the frame transmission rate is low. A busy real-time communication in a star topology network creates conditional switching probabilities that remove the deterministic nature of Ethernet communication and ultimately distort the uniform time response between communications. The safety critical context in this work is airfield communications, where the European Union Single European Sky Air Traffic Management Research (SESAR) project is progressing with the aim of producing a Europe-wide unified air traffic control infrastructure [6]. SESAR proposes a management information model known as the System Wide Information Architecture (SWIM) [6], which combines many traffic streams (concerning flights, weather and so on) into one data pool that is then available with appropriate subscriber access control to those that need it, such as airlines and air traffic control. The proliferation of connections inside this network opens up many issues of operation, maintenance and security. The provision of critical networking capability to each application thus offers enhanced prospects for network operation. Busy real-time airfield communication systems such as the SWIM architecture have many delay variations. This is the key factor for designing a traffic transmission and management system that removes this delay uncertainty. Priority Ethernet frame queuing [7] addresses this uncertain frame transmission issue by embedding an arbitrary priority number within an Ethernet frame to correct this stochastic delay variance with data throughput. This method works by shifting priority frames to be transmitted first. Here, we propose an alternative method which we term a network traffic oscillator (NTO).

We have found that creating an oscillation in frame transmissions with varying frame size management (traffic load) produces a deterministic arrival rate that increases the precision of transmission and removes delays. This method removes unnecessary additional random delays created by switches and digital switching bandwidth. Network switches have buffers so that when the frame switching input rate is higher than the output rate, frame congestion delay is created relative to the number of frames in the buffer. Subsequently, a large frame uses more of the link transmission bandwidth, and creates additional time delay when there are many large frames in the system.

In this paper, a NTO corrects these modern communication

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delay problems by dynamically rearranging network resources to suit different network traffic conditions. This paper investigates the NTO in four parts. Section II contains an explanation of the NTO design, followed by section III which describes the Ethernet simulation employing the NTO method in a star network created from a SWIM environment. Section IV contains the results produced from using the NTO to deliver deterministic response times and create predictable traffic loads in the system; the section also discusses the findings. Finally conclusions are presented in section V where we summarize the benefits of the NTO approach for real-time critical networking, where it delivers a predicable packet arrival rate without dedicated circuits in the presence of random background traffic. This is a significant step forward in the delivery of deterministic service using modern switching technology and the Ethernet protocol.

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II. Network Traffic Oscillator

The concept of the NTO is the transformation between the number of frames or *packets per second* P(t) and the frame size or *payload per packet* R(t). Packets are often regarded as a network layer terminology and frames as data-link layer but here this arbitrary division is overcome to connect the two layers and create a critical network suitable for continuous real-time communication. The bigger the frame size, the greater the resultant network loading in terms of larger buffers and longer queues. Similarly, the network workload is also increased by a large number of frames. Managing the frames by oscillating between the number of frames and the frame size, can dramatically improve the network performance by actively matching the available network resources to the application transmission. A network that is overburdened with large frames will continue to exceed each frame service time unless these are broken down into smaller units. Similarly, congestion from multiple frames can be reduced by combining consecutive frames (that have the same destination) into one long frame. The two busy traffic conditions experienced in the network can thus become interchangeable depending on the current network workload. Frame transmissions are divided by their application protocol, destination and its critical time window. This level of division removes any hidden obstacles within the network, and re-orders network traffic to suit the network availability. Thus the NTO increases frame transmission punctuality by dynamically allocating transmission based on the network arrangement.

The NTO has two critical model components, a buffer and a flow controller. At the input to the device, the payload per packet is R_{IN} and at its output, this becomes R_{OUT}. The difference arises from the action of the flow controller (R_F) in proportion to the rate of change of output packets per second.

$$R_{\mathrm{OUT}} = R_{\mathrm{IN}} - R_{\mathrm{F}} \tag{1}$$

Without the device, we have a buffer that accepts an input stream of pin packets per second and divides it into packets of size B

$$R_{\mathrm{IN}} = R_{\mathrm{B}} = \frac{1}{B}\int P_{\mathrm{IN}}(t)dt. \tag{2}$$

Using the NTO:

$$R_{\mathrm{OUT}} = \frac{1}{B}\int P_{\mathrm{OUT}}(t)dt. \tag{3}$$

Now, for the flow controller:

$$R_{\mathrm{F}} = F\frac{\mathrm{d}P_{\mathrm{OUT}}(t)}{\mathrm{dt}}. \tag{4}$$

So from (1)-(4) we can obtain the Laplace domain transfer function of the NTO by recognising the resonant frequency $\omega_n^2 = (BF)^{-1}$:

$$H_{\mathrm{NTO}}(s) = \frac{\tilde{P}_{\mathrm{OUT}}(s)}{\tilde{P}_{\mathrm{IN}}(s)} = \frac{\omega_n^2}{s^2+\omega_n^2} \tag{5}$$

The resonant frequency is low compared to the rate of packet arrival at the device and so the response observed will be that to a step input of size $\bar{P}$, the mean arrival rate in packets per second, thus:

$$P_{\mathrm{OUT}} = \bar{P}\{1 - \cos(\omega_n t)\}. \tag{6}$$

Thus, the buffer collects a multitude of frames in a period of instances into a longer payload per packet R. The flow controller divides a long payload per packet into multiple packets per second depending on the network workload. The directly opposing nature of the functions of these two components creates traffic oscillation patterns within packet transmission. The buffer factor B is the collection of frames and measures the level of traffic load in the network, while the flow controller increases or decreases the frame flow rate F based on the traffic load. These varying transmission patterns create a critical time response window between workload (frame size) and channel division management (frames per second). Oscillating traffic is managed within network switches and physical packet queuing buffers to deliver deterministic arrival rate transmission.

III. Methodology

A simulation was conducted using the setup in figure 1, where a star topology contained three main network switches (servers) that directed traffic depending on the application loads. Each server transmitted and processed data for time critical communication; non-time critical communications were added in later by client terminals (PCs). The servers used NTOs for time critical transmission with oscillation frequencies fixed per application specification to produce a traffic load for link capacity planning. Higher oscillation frequencies could be achieved by varying the buffer size in conjunction with the flow rate, depending upon the level of urgency per packet transmission. The highest priority (highest frequency) was given to those application protocols that transmit with relative low traffic loads with the shortest time response windows. Each application was assigned its own buffer to regulate the payload per packet, and its own flow controller to break down large payloads into appropriate rates in terms of packets per second. The simulation investigated the effect of time critical communication using the example of a radar server to the air traffic control tower and other servers. Radar information was being fed into a

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NTO, while other commercial communications (non-time critical applications) were also transmitted into the same network on an ad-hoc basis (non NTO). The measurements were conducted from the server client perspective.

A. Air Traffic Radar Information Transmission

The radar information in the network maintained a constant payload per second, D(*t*), which is the product of R(*t*) and P(*t*). Thus, these two could vary without changing the application network load, so long as their product remained constant. All data transmissions were fed into a NTO, where the buffer controlled the level of packets in the device by adjusting the level of the packet buffering input rate (*B*). The flow controller controlled network congestion by adjusting the packet flow rate (*F*). The total radar transmission system always adhered to the total payload transmission rate, D(*t*), designated in the transmission specification (figure 2).

B. Oscillation controller

The oscillation frequency was designed to meet the application specification required for transmission update. In general, application transmissions that have a low payload transmission rate, D(*t*), and low time response time window should preferably oscillate faster since higher oscillation cycles produce response updates in the system more readily. The system factors of buffering rate (*B*) and flow rate (*F*) could be adjusted to cater for these specifications in the simulation.

C. Network payload distance metric calculation

An NTO based network requires strict network resource management. Each network link must update its link capacity and reflect its information before assigning transmission. Dynamic network link capacity updating is crucial to maintain the Quality of Service amongst other real time critical applications (based on input measurement rather than another network management feedback protocol). Rather than using overhead (packet network information) to direct network traffic, flow can be directed using application frequency analysis. Frame overhead not only increases buffering delay by encumbering each frame with a larger payload, but it also restricts the level of freedom for network switching to manage traffic. Buffering delay is caused by large payload frames and congests the network by uncertain frame rates.

Using the NTO, the transmission of payloads with a fixed payload per second, D(*t*), by application protocols guarantees oscillatory periodic transmission rates of both frames P(*t*) and frame sizes R(*t*). The two quantities P(*t*) and R(*t*) are ninety degrees out of phase using the NTO because of their sinusoidal nature and the relationship between them. The NTO parameters combine to deliver a deterministic payload per second D(t) = R(*t*)P(*t*). Thus a switching arrangement is achieved to remove network delay completely (the delay is the measurement between two payload transmissions). The transmission rate, D(*t*), is maintained consistently in a network to ensure the lowest minimum distance between the source and the destination.

When a continuous transmission uses a large payload per packet resource, it should also use less of the packet per second resource. These two parameters, R(*t*) and P(*t*), create the payload distance of the link. To illustrate the fundamental concept, we consider transmission between nodes N_A and N_B via an intermediate node N_C as shown in figure 3. N_A has the (packet, payload) coordinates (P_A, R_A) and N_B the coordinates (P_B, R_B). That is the number of packets generated in one second by A is P_A with a payload per packet R_A. We can thus define a payload distance for link AC by the square root of the sum of the squares of P_A and R_A. This may be converted to a time T_{AC} by dividing by the payload per second value for the link N_A-N_C, which we denote by d_1:

$$T_{AC} = \frac{\sqrt{P_A^2 + R_A^2}}{d_1} \tag{6}$$

Considering the transmission from N_C-N_B, a similar argument may be made to give a time over the link BC, with payload per second d_2, of:

$$T_{CB} = \frac{\sqrt{P_B^2 + (R_B - R_A)^2}}{d_2} \tag{7}$$

The two source rates P_A and P_B are fixed as is the total payload per packet at N_B. Therefore, the time is minimized by finding the optimum value of R_A by differentiating the total time T_{AC}+T_{CB} with respect to R_A. .

Critical Networking encourages *application* payload per second to be the same as the *link capacity* payload per second transmission rate. This method allows the network switching process the freedom to delegate other link resources for other real-time critical applications and transmit non-critical application when the network becomes available.

IV. Results and Discussion

There are two types of transmission in an Ethernet system, continuous and discrete. The former is normally large payload transmission over a long period of time, whilst the latter is generally a smaller payload over a shorter period of time. The NTO enables the time-critical accommodation of continuous transmissions such as live radar feeds needing a specified transmission window time, which were treated as a series of discrete communications in the past. The NTO allows continuous real-time transmission to be more flexible (interchanging between P(*t*) and R(*t*) transmission) for link capacity management, while operating within the time response design of the application (one over the payload per second). NTO continuous real-time transmission fixes the link capacity usage of the network. As a real-time application transmission is oscillating, other real-time applications can use any other available link capacity resource. Other continuous application transmissions are encouraged to transmit data out of phase with all existing continuous transmissions; this reduces the knock-on effects of increasing payload distance from payload per packet, R(*t*) and packet per second, (P(*t*)).

In figure 4, the results show that continuous real-time application transmissions can co-exist with normal commercial applications such as e-mail, database access and server access created by user terminals, which do not require NTOs as they can use frame overhead to direct their

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transmissions. Link resources are allocated to NTO transmissions first and thus the response time of these is deterministic as the link always allocates the same resources to these communications. The clear result is that servers 1, 2 and 3 deliver deterministic service to the real-time applications despite the presence of variable traffic loads in the network, including random data bursts from the background applications. This demonstrates that Ethernet has the capability to deliver the required service to the radar traffic in an airport scenario without dedicated links.

Although critical networking could in principle be achieved without an NTO, since it concerns maintaining the minimum payload distances in a link, the level of optimization required would need advanced knowledge of each real-time continuous transmission behavior. This is impossible when any applications can use the link by adding in the correct frame overheads.

Often sudden discrete communications that are non-time critical unintentionally offset the payload distance (P(*t*) and R(*t*)) of time critical communications. Priority queuing [7] is difficult to achieve given the unknown frame arrival rate of each real-time critical communication session. Links that have a large bandwidth (in bps) can transmit payloads faster, however increasing the application payload, D(*t*), per second due to this extra link capacity also creates application payload distortion effects. This is not noticeable when the application transmits discretely (not treated by NTO), but noticeable when the continuous transmission is managed by the NTO. The level of distortion is directly proportion to the different payloads per second between the two link bandwidth technologies. This distortion can be repaired by adding phase shifts to the NTO frame transmission and to the payload per frame. Link capacity management can be easily simplified by just maintaining the same payload per second regardless of the underlying switching bandwidth.

V. Conclusions

As the size of a network increases, resource planning is increasingly difficult when the network relies solely on overheads to direct traffic. Worse still, overheads also cause larger payloads amongst frame transmissions since bigger networks naturally need bigger frame overheads i.e. larger addresses, greater frame padding, more information for additional multilayer network services [3] and support protocols for frame diagnostics. Such overheads introduce both buffering problems and also additional failures in frame transmissions via overhead errors. Frame overhead is useful given large dedicated bandwidths and link capacities but offers diminishing returns when the bandwidth and link capacity are low. Although each frame can be identified by using a frame capturing tool, this level of frame quality assurance only measures the quality of the information presented; it has nothing to say concerning the reason for the delay of the frame. It is infeasible to operate real-time critical communications in an environment where they may be delayed by discrete, non-time critical commercial messages, which should give priority to the real-time needs. Here, we have illustrated the utility of the NTO concept to address this problem and offer real-time deterministic performance in an Ethernet network also carrying other non-real time applications. The use of payload distance to quantify the performance is facilitated by the NTO, which delivers a controlled traffic stream into the network. The real-time traffic is shielded from the effects of users sending large non-time critical payloads by the NTO. By managing the transmission rate at the input to the network, flow management is also made simplified since the uncertainty in frame arrival times is removed reducing congestion. An uncertain arrival rate transmission discourages any effective advance routing planning. Network resource wastage such as low data utilization occurs because low payload frames are kept in a buffer even when the link capacity is perfectly able to handle them –this problem is removed using the NTO. In short, we have shown that Ethernet can deliver deterministic service to critical real-time applications without dedicated links and in the presence of random traffic from other applications.

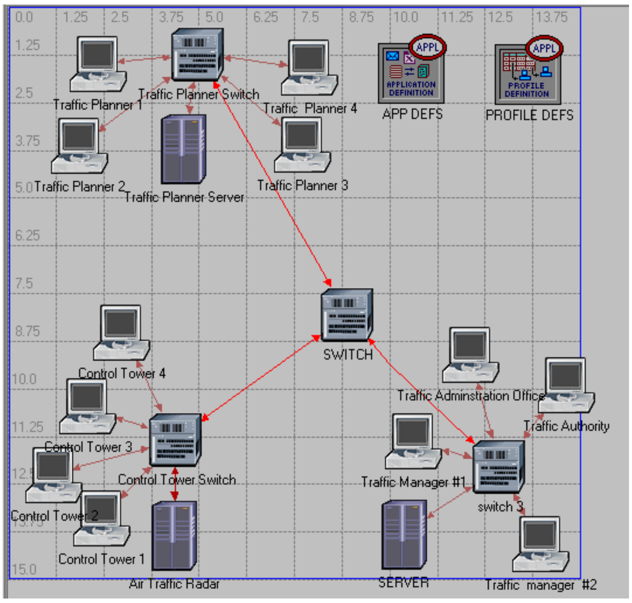

Figure 1: Real-time critical Ethernet network simulation designed to mimic the air traffic SWIM infrastructure in an airport.

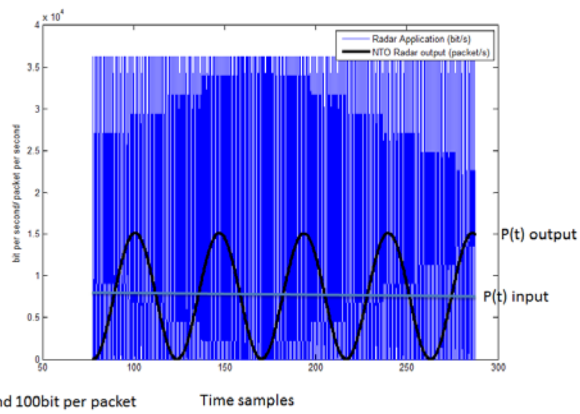

Figure 2: NTO oscillation, dividing between frame sizes and number of frame per second transmission.

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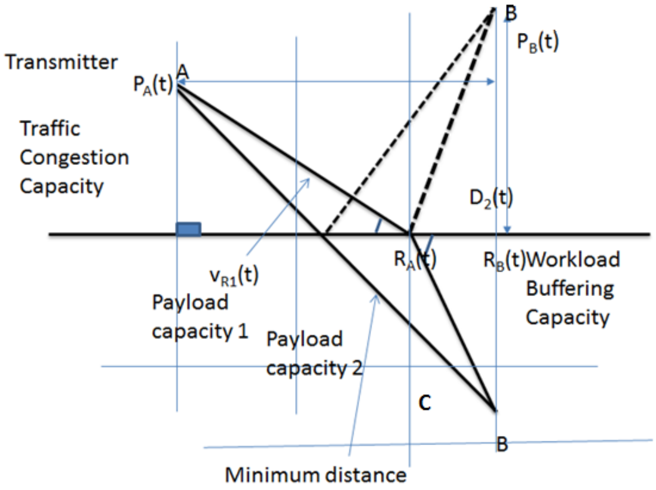

Figure 3: The communication payload distance is hypotenuse of the triangle formed by P(t) and R(t); critical networking minimizes the transmission time across the two links.

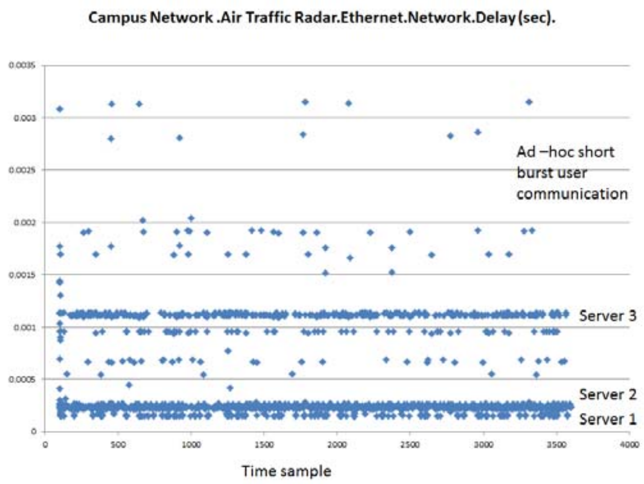

Figure 4: The servers show deterministic response times for time critical communication using NTO; non-time critical transmissions are free to transmit after all time-critical communication has been handled.

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