A PERFORMANCE STUDY OF SOURCE CONCATENATION IN MIL-STD 188-220B

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I. Introduction

Network Protocols traditionally send packets either as fixed cells (ATM) or variable sized data (TCP) with a maximum size, specified by the Maximum Transmission Unit (MTU) [1]. In both cases the packets are sent as soon as data is ready. In most cases the size of the packet sent is much lower than the MTU. Typically if the packet size is increased, the average throughput obtained from the channel increases, usually accompanied by increased average delay for each packet [2]. The layer where these effects are most pronounced is the data link layer. But in most protocols, the data link layer is usually powerless to control the size of any given transmission because that is dependent on the upper layers which hand down the packet.

In certain networks, the channel bandwidth is very limited (a tactical battlefield network is a very good example) and a heavy demand on its resources from a large number of users with varied traffic is quite capable of causing a drastic slowdown of the networking machinery [3], [4]. Also the low bandwidth results in increased channel access time for a packet, further worsening the throughput of the network.

For the reasons stated in the above paragraph, the MIL-STD-188-220B [5] protocol suite for Combat Net Radio provides a feature called *Packet Concatenation* in both the physical and data link layers. Since the channel access time for a packet is relatively large, it is highly advantageous for a node to transmit as many packets per frame as possible, each time it gets access to the channel. Of course this can be done only if there are multiple packets waiting for access to the channel, when the node gets the channel. A single data link Protocol Data Unit (PDU) can contain multiple data link Service Data Units (SDUs).

The data link frame consists of the transmission header in the beginning and the "Interior Data Frame", which consists of destination addresses, control data, information and frame check sequence. There can be multiple Interior Data Frames in one data link frame (Figure 1). From the standard [5]:

".... The sending station may concatenate any PDUs....by using one or two flags to separate each PDU. All receiving stations shall be able to deconcatenate the reception into separate PDUs. The combined length of the concatenated PDUs,...., may not exceed the established maximum PDU size for a single PDU...."

In this paper, we describe the results of a simulation study of packet concatenation in MIL-STD 188-220B. The aim of the study was to get a better understanding of the performance implications of this feature and to explore how concatenation would affect throughput and delay at various nodes in the network in the presence of symmetric as well as asymmetric traffic.

Prepared through collaborative participation in the Advanced Telecommunications/Information Distribution Research Program (ATIRP) Consortium sponsored by the U.S. Army Research Laboratory under the Federated Laboratory Program Cooperative Agreement DAAL01-96-2-0002. The U.S. government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation thereon.

II. Simulation

We constructed an Opnet [6] simulation study to explore the performance impact of concatenation at the data link layer of MIL-STD 188-220B. We assumed a non-persistent CSMA protocol in a network with 20 nodes. Fixed-length packets arrive at each node with

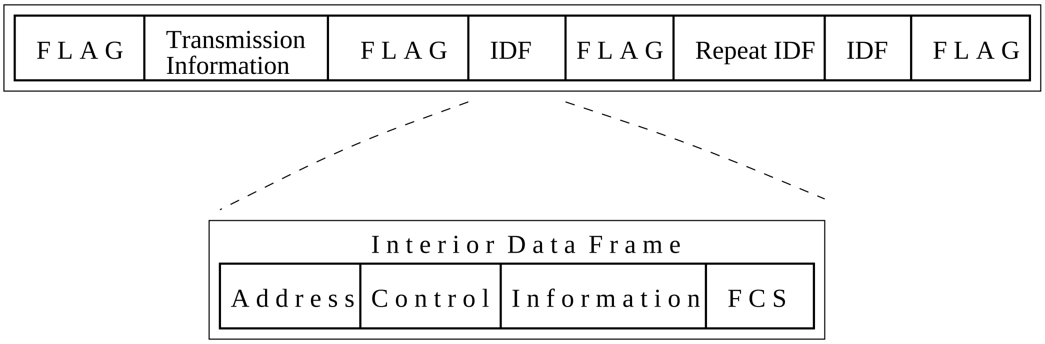

Fig. 1. Data-link concatenation.

independently exponentially distributed inter-arrival times. We imposed a maximum limit on the size of a transmitted PDU of C user packets, where C is called the Concatenation Limit. We studied concatenation limits in the range of 1 through 10 (a concatenation limit of 1 corresponds to no concatenation at all.)

We studied traffic scenarios where a special node had a traffic intensity that was different from the traffic intensity at the remaining nodes. The intention was to study the impact of concatenation on fairness: is it possible for the special node with a heavier traffic to virtually "capture" the channel and thereby starve the traffic at the other nodes?

The main parameters used for the simulation were the concatenation limit and the arrival rate of the Regular and Special nodes. Also used to limit the duration of the simulation are the time that the simulation is to run and the maximum number of packets that are to be received. From the system, data is collected for number of packets transmitted, number of packets received, and end-to-end delay for regular and special nodes. These data are then used to calculate the average number of packets per transmission, the fraction of the throughput that belongs to the special and regular nodes and the end-to-end delay. Some of the most important characteristics that were studied are the end-to-end-delay and the fraction of the throughput of the Special and Regular nodes.

III. Results

Using these simulations, certain observations were made of the effect of traffic patterns on the average level of concatenation, the end-to-end delay and the throughput of the network.

A. *Average packets per transmission*

The average packets per transmission gives an idea of how effective the concatenation is for the nodes. If the maximum level of concatenation allowed is only 2 packets per frame, then the average packets per transmission can be a maximum of only two (this maximum cannot be reached under low loads, when the network is free, as the node can transmit more often and does not wait for another packet). The effect of traffic on the average packets per transmission is very much what is to be expected. As the load increases on the node (and therefore on the network), packets are concatenated more often. This is because the channel access time for the node increases and so the node is forced to wait. During this time another packet could get ready for transmission and the node can concatenate the two (or more) packets.

- Special Node: The average packets per transmission of the Special node increases with the arrival rate of the Special node (Figure 2), as is to be expected from what is explained in the previous paragraph. This characteristic also increases as the concatenation limit increases. This implies that more packets can now get concatenated.
- Regular Node: The average packets per transmission of the Regular node remains constant over the arrival rate of the Special node. There is not much change as is with the Special node. Interestingly, this characteristic also does not show much variation to the concatenation limit (Figure 3). In fact the maximum concatenation achieved by the Regular node is not more than 1.15, even when the concatenation limit is set to 10. This can be attributed to the fact that the arrival rate of the Regular node is quite low as compared to that of the Special node. So each node would definitely get a chance to transmit its

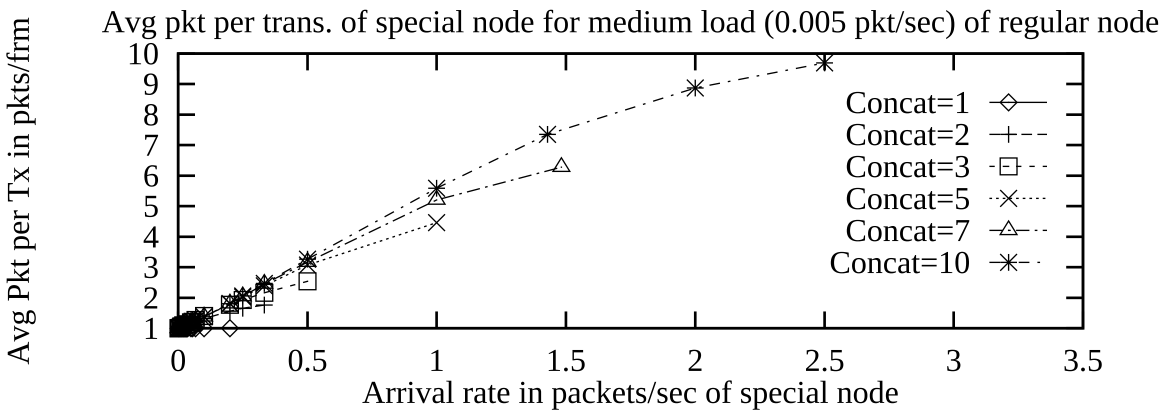

Fig. 2. Average number of packet transmitted in each frame for the special node, when the regular node is at medium load (0.005 packets/sec).

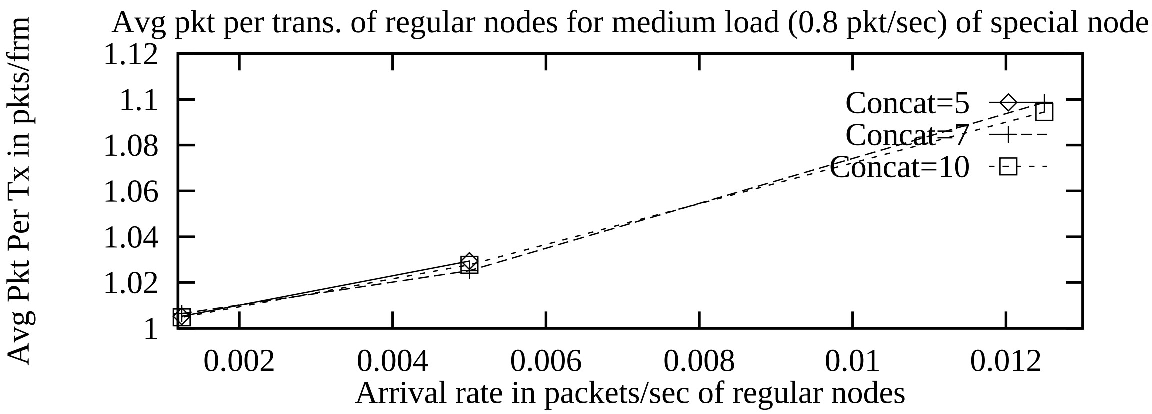

Fig. 3. Average number of packets transmitted in each frame for the regular node, when the special node is at medium load (0.8 packets/sec).

packet before another packet gets ready for transmission.

B. End-to-end Delay

The end-to-end delay gives us an idea of the average time a packet is going to take to go from the transmitter to the receiver. This delay, of course, also includes the delay experienced waiting for the channel to get free. Generally we would expect that the delay would increase with load and in fact we find that to be true. Delay also decreases with increasing concatenation, as the packets don't have to individually wait for the channel to get free, as is the case when no concatenation is allowed.

• Special Node: The delay, as explained in the above paragraph, increases with the increase in arrival rate of the Special node (Figure 4). In fact at a certain point the delay suddenly increases to very high values, which shows the instability of the system. The delay decreases considerably when concatenation is increased, again as explained in the first paragraph of this section. As concatenation is increased, more packets are able to get transmitted at the same time and so the overall average delay of the transmission is reduced. It reaches an "all-time" low when the concatenation limit is set to 10 and the regular nodes have a very low load (arrival rate of 0.00125 packets/sec). The dependence on the arrival rate of the Regular node is quite similar to its dependence on the arrival rate of the Special node (Figure 5). The delay increases as the arrival rate of the regular node increases.

• Regular Node: The dependence of the end-to-end delay of the Regular nodes on the factors of arrival rate of the Special Node (Figure 6), concatenation limit and arrival rate of the Regular nodes (Figure 7) is pretty much similar to that of the Special node. There are no exceptions to be found at all and so we

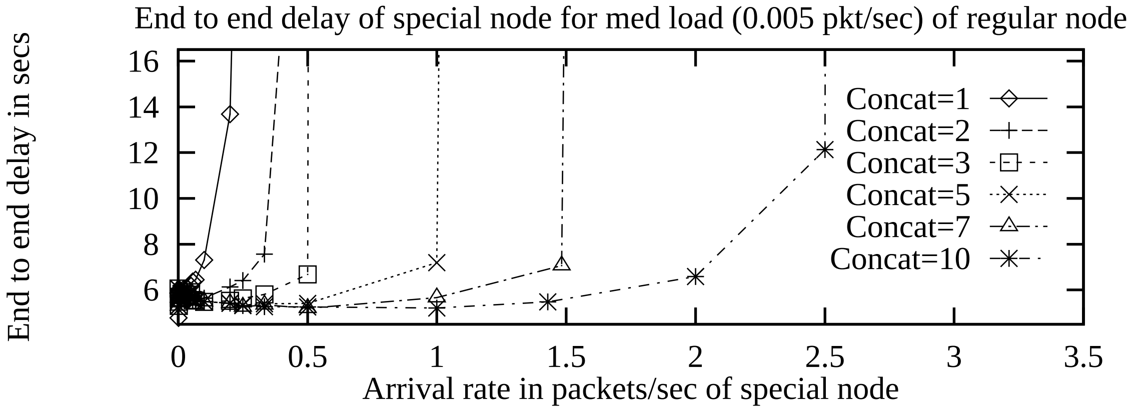

Fig. 4. The end-to-end delay experienced by packets of the special node, when the regular node is at medium load (0.005 packets/sec).

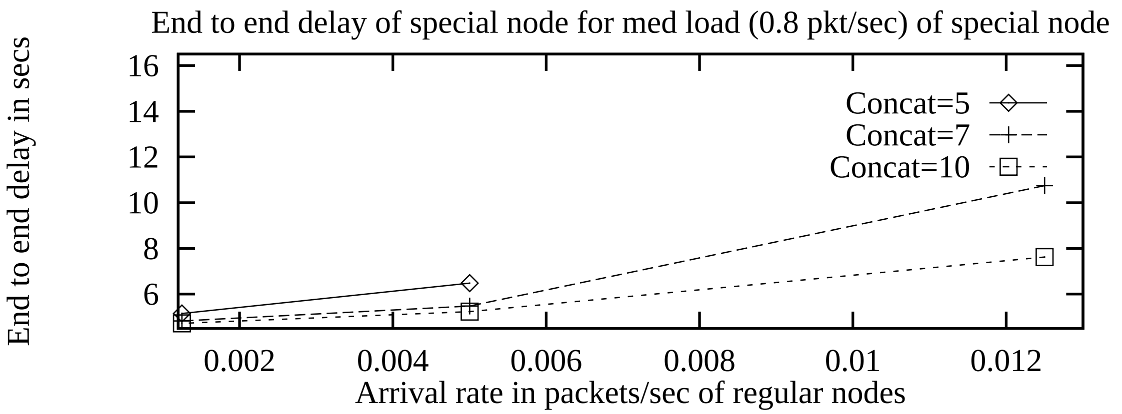

Fig. 5. The end-to-end delay experienced by packets of the special node, when the special node is at medium load (0.8 packets/sec).

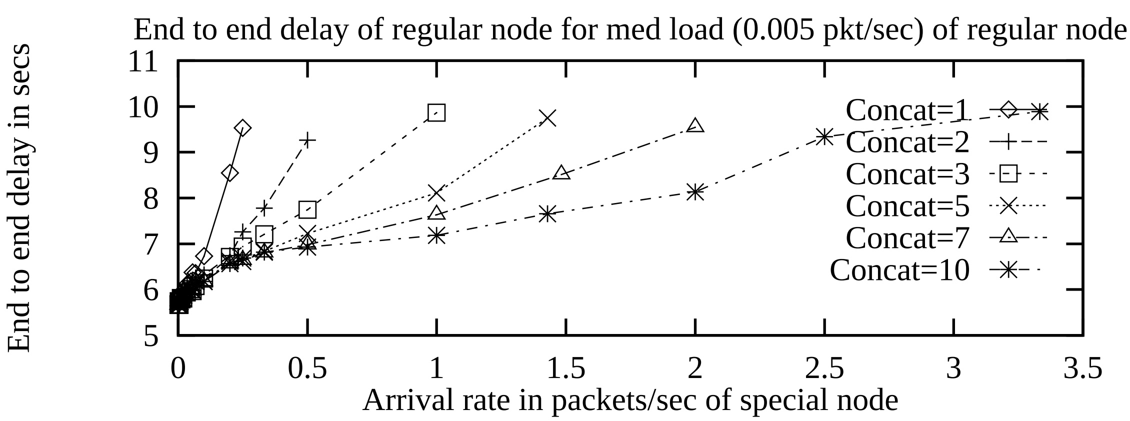

Fig. 6. The end-to-end delay experienced by packets of the regular node, when the regular node is at medium load (0.005 packets/sec).

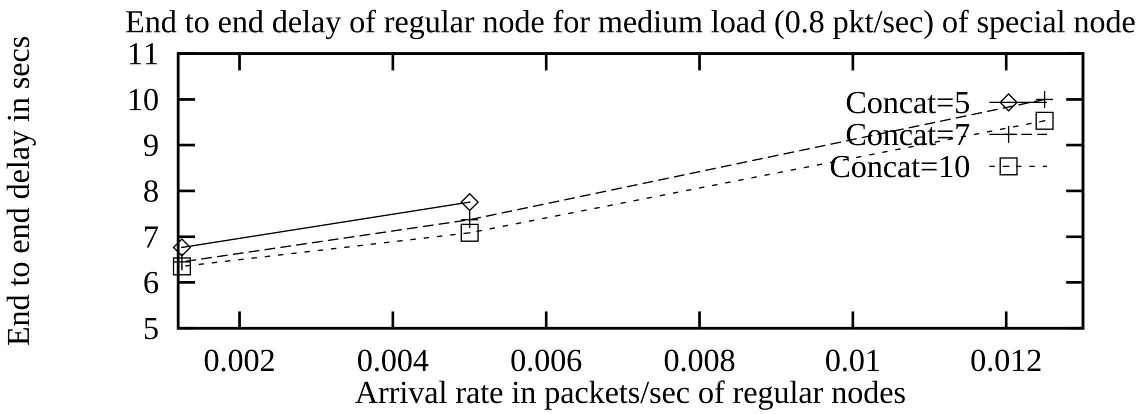

Fig. 7. The end-to-end delay experienced by packets of the regular node, when the special node is at medium load (0.8 packets/sec).

can safely conclude that the delay follows the pattern that we expect.

C. Fraction Of Arrival Rate and Throughput

This characteristic allows us to analyze what percent of the overall throughput belongs to the Special node and what belongs to the Regular nodes and whether this percent is consistent with the percent of traffic that is generated by the Special and Regular nodes. This helps us see how the traffic pattern and concatenation affects the transmission capabilities of the Regular and Special nodes.

It was observed that the fraction of throughput that belonged to the Special (Regular) node increases (decreases) as the arrival rate of the Special node increases (Figure 8). This is quite expected because now the Special node has more packets to transmit than the Regular nodes do. So it occupies most of the bandwidth of the network. More interestingly, it was also found that the fraction of throughput of the Special (Regular) node *does not depend on the concatenation*. Irrespective of the concatenation limit, the fraction of throughput was found to follow the same pattern. This only shows that the Special node occupies a fixed amount of the network bandwidth irrespective of the concatenation limit. The amount of bandwidth it occupied depended solely on the arrival rate of the Special and Regular nodes and not on the concatenation limit.

This proves that the protocol is fair, when performing channel access, and does not discriminate against the regular nodes simply because they have less traffic to send.

D. Maximum Throughput Over Concatenation

Maximum throughput over concatenation helps us understand how concatenation affects the total throughput of the network. Since concatenation typically reduces the traffic of the network, by combining a number of packets in one single frame, it reduces the channel access time of the nodes. As a result of this, the delay of the system, as well as the traffic in the network, reduces. Since the bandwidth of the network is quite low, very high traffic can lead to unstable systems with very high delays and very low throughput.

In the simulation that we performed, the system was allowed to run till it reached instability. Since higher concatenation reduces the chances of instability, it was found that more traffic could be sent through the network. Therefore the arrival rate of the Special node (which is increased till the system reaches instability) can be increased to very high values. As we have already seen, the total throughput of the network increases when the arrival rate of the Special node is increased. Therefore increasing the concatenation increases the total throughput of the network (Figure 9).

Figure 9 also shows that lowering the arrival rate of the regular node increases the maximum throughput at a given level of concatenation. Lower arrival rate of the Regular node implies that the traffic due to the Regular node is less, therefore the arrival rate of the Special node can be further increased. Since the total throughput increases faster with increase in the arrival rate of the Special node than with increase

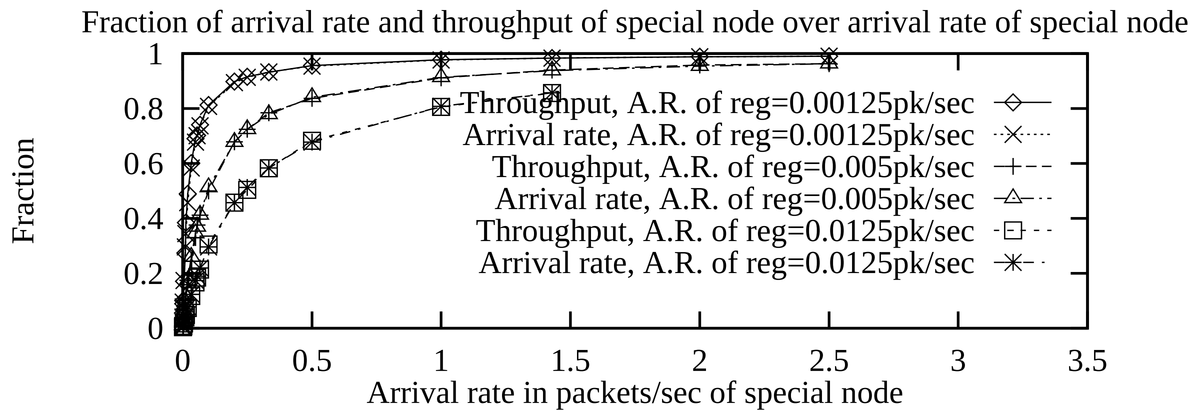

Fig. 8. Fraction of arrival rate and fraction of throughput of the special node over the arrival rate of the special node. Keys: A.R. - Arrival Rate.

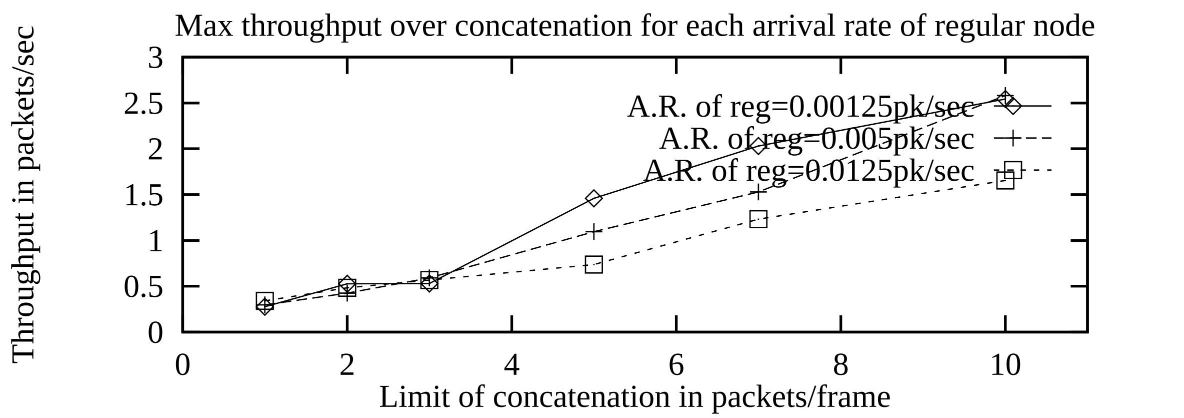

Fig. 9. Maximum throughput of the network for different concatenations. Keys: A.R. - Arrival Rate.

in the arrival rate of the Regular node, the maximum throughput for that particular concatenation is higher.

IV. Conclusion

The effect of data link layer source concatenation using MIL-STD-188-220B was observed. It was found that concatenation did not affect the fraction of throughput of the nodes. It was also found that the protocol is very fair and the node that generated the most data was given more access to the channel. This study will allow us to examine how packet concatenation can be used effectively in the construction of dyanamic routes for transmission over a battlefield network with ad-hoc topology [7], [4].

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U.S. Government.

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