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Introducing a Collaborative Congestion Control Based on TFRC

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Abstract—**Wireless ad-hoc networks, composed by PDA-like mobile equipments, are the technologies used in pervasive ambient networks. These environments opens applicative perspectives allowing the cooperation of hierarchical user groups which are mobile in the context of emergency operations (EO). In this paper, we introduce a novel "collaborative" congestion control mechanism at the transport level allowing for improving the QoS. When available resources are not enough to offer an acceptable level of QoS for all connections, the approach consists in improving the highest priorities connections while maintaining the fairness and friendliness properties regarding the other connections. We present the results obtained by ns-2 simulation that allow to determinate as well as validate the work hypothesis for such a "collaborative" congestion control.**

Keywords: Congestion Control, collaborative activity

1 Introduction

Recent advances in computing and networking technologies enable the deployment of complex group communication activities such as emergency operations (EO). These activities involve mobile users cooperating in a common mission. Such activities have several time-varying communication requirements that depend on the criticity of the activity, on the utilized media type (audio, video) as well as the evolution of the activity. These activities are also constrained by the machines and networks resources like energy, memory or bandwidth.

End-to-end congestion control is a required mechanism to avoid congestion collapse in the network and to optimize the Quality of Service (QoS) in terms of bandwidth, throughput and delay. The congestion control provides algorithms designed to share the bandwidth in the whole Internet in a way that is fair. Several work have been carried on in order to maintain this fairness in novel networking environments such as ad-hoc and wireless mobile networks [1, 2, 3]. Emergency Operations (EO) are generally deployed in such environments. Nevertheless, in the context of EO, it could be relevant to give priorities to some communications between specific users depending on their role or on the criticity of a discovered situation. The approach presented hereafter consists in enhancing an end-to-end congestion control mechanism in order to take into account the priority features of the EO.

The paper is organized as follows. Firstly, the various existing approaches in the literature for congestion control mechanisms are presented. Then, the context of the EO and their particular QoS requirements are presented. In section III, the basic principle of a collaborative congestion control algorithm is discussed. Section IV presents the results obtained with the ns-2 simulator which validate the approach and validity hypothesis.

2 State of the art, Context and Motivations

The following subsection presents the state of the art and the context of our contribution. First, the various mechanisms for congestion control are presented, then the context of Emergency Operations (EO) is presented illustrating why none of these mechanisms is suitable.

2.1 Congestion Control

Congestion control on the Internet is a compulsory mechanism [4]. Indeed, an increasing deployment of Best Effort traffic lacking end-to-end congestion control could lead to congestion collapse of the Internet. In addition, when an application does not implement end-to-end congestion control, the bandwidth is unfairly utilized. This results in applications that implement an end-to-end congestion control being penalized.

There are two kinds of congestion control [5] : window-based and rate-based.

Window-based congestion control, like the one used by TCP [6] consists in using a congestion window that limits the sending of data in the network. The losses are considered as a network congestion and imply the reduction of the congestion window.

Rate-based congestion control is more suitable for transporting multimedia contents because it allows smoother rate variations than window-based mechanisms. Exist-

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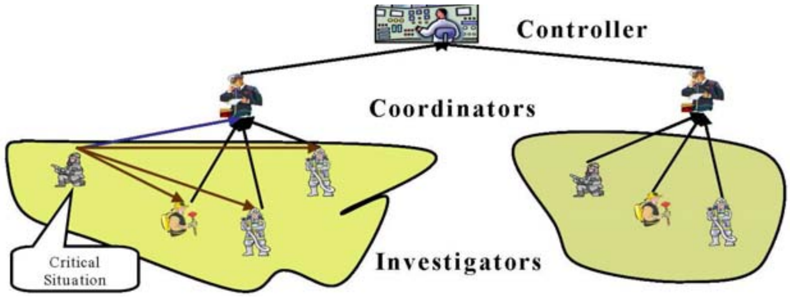

Figure 1: Hierarchical Organization in Emergency Operations

ing rate-based congestion controls can be source-based or receiver-based algorithms. Each of these mechanisms can be further classified in two categories: probe-based and model-based congestion control.

2.1.1 Probe-based rate control

For probe-based rate control, if the congestion control is source-based, the sending rate is adapted by probing for the available bandwidth. The source monitors a QoS parameter (the loss rate for example). Some thresholds are defined for this parameter and the sending rate is modified when the thresholds are violated.

If the congestion control is receiver-based, the approach (mostly used in multicast communications [7]) consists in probing the available bandwidth by joining/droping a layer which implies an increase/reduction of the receiving rate.

2.1.2 Model-based rate control

For model-based rate control, if the congestion control is source-based, the available bandwidth is explicitly estimated with a model based on the throughput model of a TCP connection. This model is used in the TFRC mechanism (*TCP-Friendly Rate Control*) [8] which's formula is given by equation (1).

$$X = \frac{s}{R\sqrt{\frac{2bp}{3}} + t_{RTO}(3\sqrt{\frac{3bp}{8}})p(1+32p^2)} \qquad (1)$$

with X the rate in bytes/s, s the packet size in bytes, R the RTT in seconds, t_{RTO} the retransmission timeout in seconds, $p \in [0..1]$ the loss event rate computed by the receiver.

If the congestion control is receiver-based, the approach consists in using equation (1) to join the best suited layer [9].

In conclusion, congestion control is a key mechanism to improve the QoS of a network. It is based on the principle of a fair sharing of the available bandwidth among all the users. Indeed, the priorities between the users or the connections are not considered.

2.2 Emergency Operation and ad hoc Quality of Service

2.2.1 Emergency Operations

In crisis situation (natural disasters, . . .), the emergency operations imply the cooperation of mobile users. To support this cooperation, multimedia information (audio and video) is generally exchanged. As presented above, multimedia content has specific requirements like guaranteed throughput, bounded delay, . . . The considered environment in EO generally has not network infrastructure or only provides a limited subset of equipments. The EO participants carry mobile devices and use wireless networks with bandwidth and resources which are limited but also variable in time. Finally, as shown on figure 1, EO are generally organized in a hierarchical way. This hierarchy also generally represents the different communication links and their relative importance.

An EO team may be composed by a controller, several coordinators, and several investigators supervised by a coordinator. In this hierarchical organization, the communications between the controller or the coordinators have a higher priority than the investigators' communications. In case of lack of resources, it might be acceptable to only satisfy the QoS requirements of the controller and the coordinators. However, the evolution of the mission may lead to changes in the priorities between communications. Investigators explore the operational field, observe, analyze and report about the situation. If they discover a critical situation, it might be relevant to give them a higher priority for the communication they are having with their coordinator for sending this information.

In the context of the EOs, the QoS requirements originate from the multimedia contents being exchanged on mobile and wireless networks as well as from the communications hierarchy. There are priorities among the users and the connections due to the relative importance of the roles in the mission and also due to critical situations that modify the existing hierarchy and raise the priority of some investigators connections.

2.2.2 Quality of Service over ad hoc networks

Several approaches to QoS management in ad hoc networks have been presented in the literature. At the MAC layer, the QPART framework [12] provides stateless differentiated services by dynamically dropping low priority flows based on certain criteria such as contention window size and channel congestion level. At the Network layer, SWAN [10] introduces a distributed stateless admission control and traffic differentiation control algorithm. The Best Effort flows throughput is regulated by using delay measurements provided by the MAC layer as parameter. This approach has been further extended to take a fixed wired DiffServ network interconnection into account by DS-SWAN [11].

In EO, collaboration is an important factor and a strong bind between the application layer and a QoS management system is required. However, both SWAN and QPART are not directly invocated by the application in the communication stack. Thus, cross-layering techniques are not straightforward to implement. Moreover, participants in EO have simple relative priorities which are difficult to map to each of these frameworks' metrics system. In this paper, we introduce a Transport layer mechanism that does not involve complex cross-layering due to its high position in the stack.

In order to improving the quality of service in this context where the resources are varying and limited but communications have relative priorities, the following section presents an enhanced rate-based congestion control mechanism to take priorities between the connections into account.

3 Towards a collaborative congestion control

In order to target the applicative requirement of a congestion control which is able to take into account the relative priority of users in contexts which are highly cooperative the description and study of a preliminary solution to this problem is presented. Moreover, preliminary results aiming at validating the idea are included.

3.1 Mechanism description

In order to take communication priorities into account, our approach consists in extending the sender-based TFRC congestion control presented above [8]. In a first study, collaborations are considered to always be performed in pairs.

Note: In all that follows, the terms "collaborating" and "collaborative" are used to designate the flows that implement the modified TFRC algorithm presented hereafter. All other flows are designated by the terms "non-collaborating".

Definition: Lets E the set of connections on which the collaborative activity's data is transmitted. And let P, the absolute priorities vector such that P_i corresponds to the priority of connection E_i.

Notation: Let two connections, E_i and E_j. The collaboration between connections i and j is noted $C = \{E_i, E_j\}$

Definition: For any collaboration C, let DM a vector such that:

$$\mathrm{DM} = \begin{cases} (1,0) & \text{if } P_i > P_j \\ (0,1) & \text{if } P_i < P_j \\ (-1,-1) & \text{if } P_i = P_j \end{cases}$$

Let $TFRC$, the throughput computed by using equation (1) and δ the collaborative variation applied to this throughput. X_k, the throughput of the kth connection $\in C$ is then given by:

$$X_k = \begin{cases} TFRC & \text{if } DM_k = \text{-1} \\ TFRC + \delta & \text{if } DM_k = 1 \\ TFRC - \delta & \text{if } DM_k = 0 \end{cases}$$

Given the above, the connection which presents the highest priority will benefit from a throughput that is superior to its low priority counterpart by a value of $2 \times \delta$. Compared to a "fair" scenario, the throughput is raised by δ for the highest priority connection while it is cut by δ for the lowest priority connection.

Remark: Let D_C the overall throughput of the C collaboration, $D_C = X_i + X_j$. It is remarkable that the value of D_C is unchanged compared to a scenario where the default TFRC congestion control algorithm is used as its value always remains constant such that $D_C = 2 \times TFRC$.

4 Case Study

In order to illustrate the implementation of the above presented collaborative congestion control, multiple scenarios in which two "collaborating" connections are in presence of "non collaborating" connections are presented. Through these scenarios, the first approach to resolving the collaborative congestion control presented above is validated.

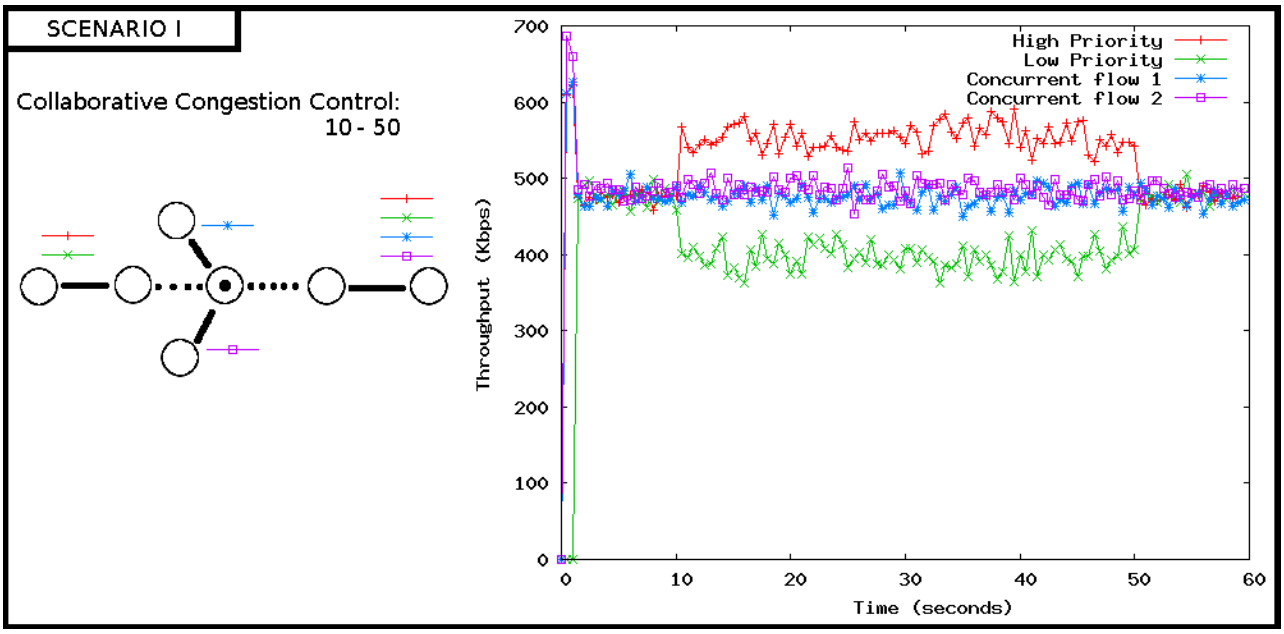

Figure 2: Scenario I - All flows follow the same path

4.1 Test scenarios description

In a first scenario, the two collaborating connections are executed such that their packets follow the exact same route through the network. In order to enssure this property, they are set up so that they share both the sending and receiving host.

In a second scenario, which aims at extending the validity of the approach, two different traffic sources generating data towards a single destination host are considered. Additionally, in this scenario, the network is loaded in such a way that the path bottleneck is always located on the section which is common to both connections.

The third scenario further extends the experimental context and hypothesis in order to determine the limits of the approach. Indeed, in this scenario, the two collaborating source don't share the same bottleneck. In this situation, the effects of the collaborative mechanism on the other connections is studied and conclusions on work hypothesis are able to be formulated.

4.2 Results

4.2.1 First Scenario

The results obtained for the first scenario are presented on Figure 2. In this scenario, the two collaborating connections share the same route through the network. They are put in competition for bandwidth with other connections such that one of the routers located on the data path is in a state of congestion (this is so the congestion control mechanism of our connections is activated)

This first study aims at demonstrating the feasibility of the approach. Indeed, the topology is very particular. However, many existing applications such as videoconference present a similar configuration (audio and video flow having relative priorities).

On the graph presented on Figure 2, it is possible to observe that all four connections in competition for bandwidth obtain, in steady state, their fair share of the bandwidth with a throughput of approximately 490Kbps (between seconds 3 and 10). The collaborative period takes place between seconds 10 and 50. During this time, it is remarkable that the connection having the highest priority obtains more resources (550Kbps) than the one with the lower priority (430Kbps). Moreover, it can be seen that this "collaboration" has no influence on the other connections which maintain their constant sending rate of approximately 490Kbps. Finally, once the collaborative period ends, the standard TFRC congestion control algorithm restores fairness.

4.2.2 Second Scenario

The results obtained for the second scenario are presented on Figure 3. In this scenario, the two collaborating connections do not share the same sending hosts. They are competing for bandwidth with other connections such that the congested bottleneck is located on the common portion of their respective paths at all times during the experiment.

A first part of the scenario between seconds 10 and 15

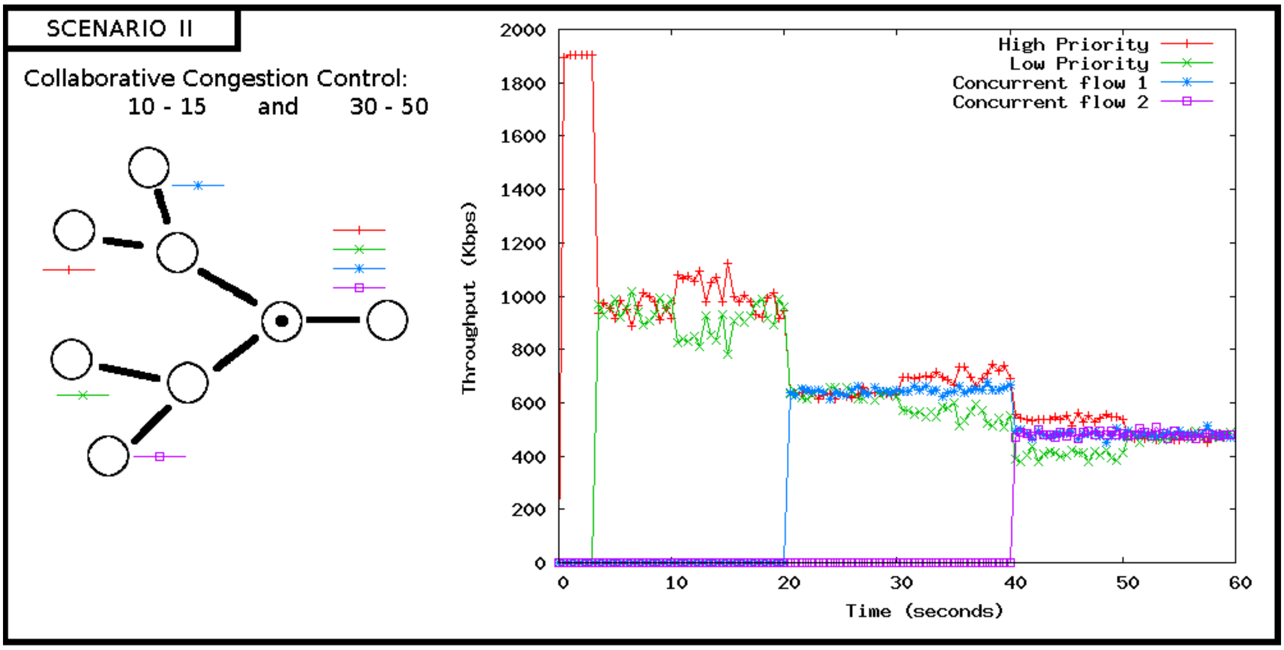

Figure 3: Scenario II - Different source nodes, common bottlneck

on the graph presented on Figure 3 aims at demonstrating that, in the absence of concurrent connections, the collaborative congestion control can be implemented between two different traffic sources if they share a common bottleneck. In a second part, a single "non collaborating" connection is started, it can be seen that a collaborative period between seconds 30 and 40 has no effect on the non collaborating connection's throughput which obtains the same share of the bandwidth as before. Finally, the arrival of a second "non collaborating" flow during the collaboration period at second 40 reduces the throughput of all the connections in the system by the same amount regardless of the fact that they are collaborating or not. The collaborative connections react to the new connection's arrival by reducing their throughput in order to make room for the new flow while still maintaining the priority induced throughput δ between them.

4.2.3 Third Scenario

The results obtained for the third scenarios are presented on Figure 4. In this scenario, the two collaborating connections originating from different hosts evolve in competition with other "non collaborating" connections. The context is similar to the second scenario with the difference that the constraint for the bottleneck to be located on the common portion of the data path no longer exists. Indeed, depending on the different connections' throughput, the bottleneck might not always be located on the common part of the route.

On the graph presented on Figure 4, a first collaboration period between seconds 10 and 15 is similar to the results obtained previously when the bottleneck was shared. However, the arrival of a first "non collaborating" connection at second 20 moves the congestion bottleneck to the upper part of the network. Given this, the collaborating connections don't share a common bottleneck after second 20. The collaboration period between seconds 30 and 50 shows that the non collaborating connection is affected by the aggressive behavior of the high priority connection. The resources are no longer fairly shared and the arrival of another "non collaborating" connection demonstrates that the behavior of the high priority connection affects all other connections.

5 Conclusion & Perspectives

After introducing the existing techniques for performing congestion control in networks, the existence of activities such as emergency operations for which the "fairness" property is not a requirement has been identified. This is mainly due to the fact that in such environment, the applicative nature of the exchanges is such that a certain hierarchy can be established between participants.

The study presented in this paper aims at demonstrating that a simple mechanism allowing to take priorities between connections into account exists. Moreover, it allowed to discover the limits of such simple mechanism given the "fairness" and "friendliness" objectives towards "non collaborating" connections.

This approach needs to be further researched, indeed,

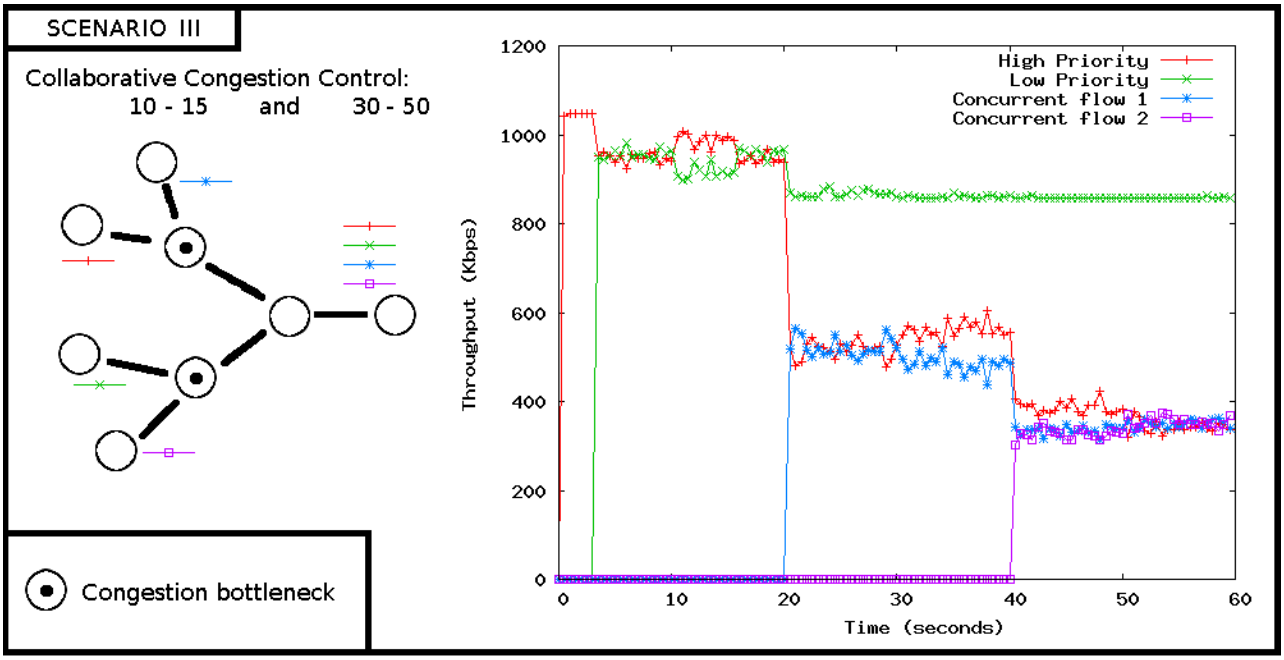

Figure 4: Scenario III - Different source nodes, different bottlenecks

work towards detecting the sharing of a common bottleneck as well as methods to synchronize the collaboration periods are to be carried on. Besides, the extension of the mechanism to n connections without an exponential growth in complexity needs to be studied.

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