Conceptual Architecture for QoS in Heterogeneous Networks

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Abstract: The advent of mobile-centric and wireless devices and the need to preserve and apply the ubiquitous Internet technology, which was originally conceived when mobility was not an issue, has posited the need to create augmented and modified models of communication that attempt to preserve the semantic integrity and transparency independent of the underlying communication infrastructure. The applications developed for mobile and wireless products that include multimedia attributes most certainly requires a provision of Quality of Service (QoS). Some of the problems in a heterogeneous wireless networks that either directly or indirectly influence the QoS are well known. These include but are not limited to reliable transport services, where reliability due to the infrastructure might prove to be liability rather then an asset, then asymmetrical nature of the traffic, and finally the problem of handoffs. In the paper, which is a report on an ongoing research, we propose an architecture that addresses the problems of the Internet technology deployment in wireless heterogeneous networks through an interesting conceptual framework. The basic architectural components of this model, once sufficiently explored and well defined, should be able to provide a desirable QoS in some aspects for the 4G networking.

1. INTRODUCTION

The ubiquitous nature of IP and hence its interoperability are considered to be fundamental for a seamless mobile Internet access also [1]. This type of access is one of the attributes of 4G systems, which support global roaming across multiple wireless and mobile networks [3]. The need to provide a spectrum of services, as well as increased coverage and reliability in a heterogeneous environment posits that there are a number of interesting problems to be solved such as QoS both in a multicasting environment and in general, authentication and security.

The satisfactory level of QoS particularly with respect to wireless links highly depends on the right traffic control strategies that will fully exploit the available bandwidth also. On the other hand, IP has been intrinsically linked to the best effort service, which might be inadequate to fulfil QoS requirements and eventual contracts [1], [3]. The problem is most likely aggravated with the fact that various wireless infrastructures in general adopt different mechanisms (most of them with some noticeable deficiencies) in order to realise the provision of the QoS contracts.

The phenomenon of congestion is clearly one of the detrimental factors to the QoS. Namely, congestion has an influence on the delay (and hence the appearance of jitter), and also on the reliability. In the last ten years there are number of successful mechanisms developed to deal with congestion. However, in a heterogeneous network the assumption that a packet loss always indicates an appearance of congestion might be flawed. This is simply because (1) a wireless link has a much higher bit-error rate, and (2) the TCP connection might be temporary down due to handoff. The result is an unnecessary invocation of some congestion recovery algorithms. The immediate effects on the network are a low link utilization and unsatisfactory TCP performance. The consequence has been reluctance in the deployment of TCP's end-to-end congestion control in networked multimedia applications with QoS requirements. These types of applications are delay-sensitive rate-based and exhibit tolerance to a certain degree of packet loss.

2. CONCEPTUAL SYSTEM ARCHITECTURE

The traffic management on the Internet with respect to congestion control [4] has a very limited choice and must rely on the window control of the end host to regulate the data rate. The wireless environment induces much more complexity due to the continuous movement of the mobile station(s). Obviously, the window control mechanisms are sufficient neither to describe nor to resolve the problems with congestion in wireless links. A pool of methods such as Snoop, I-TCP and Fast Retransmit has been proposed to address congestion management [4]. While some of these methods have been rather successful in wireless network, they are mainly dealing with the retransmission task of TCP. It is clear that there is a need for a more general approach that could eventually handle most of the traffic problems in future heterogeneous networks where it s nature is affected by the mobility also. The most reasonable solution is to deploy a snoop agent at the base station (Figure 1) that will somehow control the data transfer between a fixed host and a mobile one.

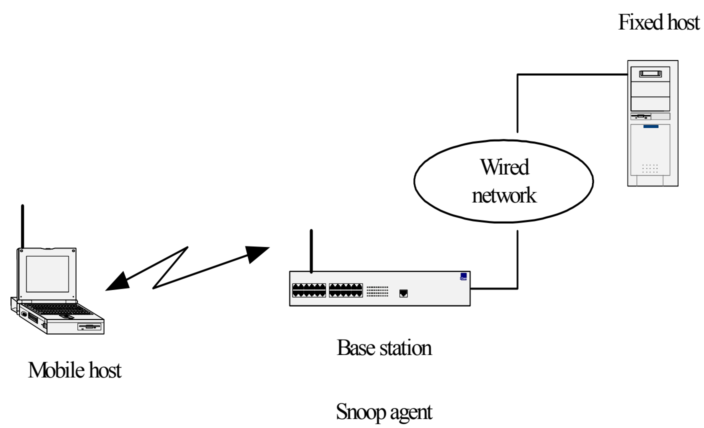

Figure 1. A single-hop wireless network with a snoop agent at the base station

Initially, the agent caches unacknowledged TCP segments (Figure 2). Then the agent performs local retransmissions of lost segments, which are detected based on duplicated ACKs from the mobile host and timeouts of locally maintained timers. In this case the intention of the agent is to hide entirely the results of the transient situation (very low communication quality and even temporary disconnection) [5].

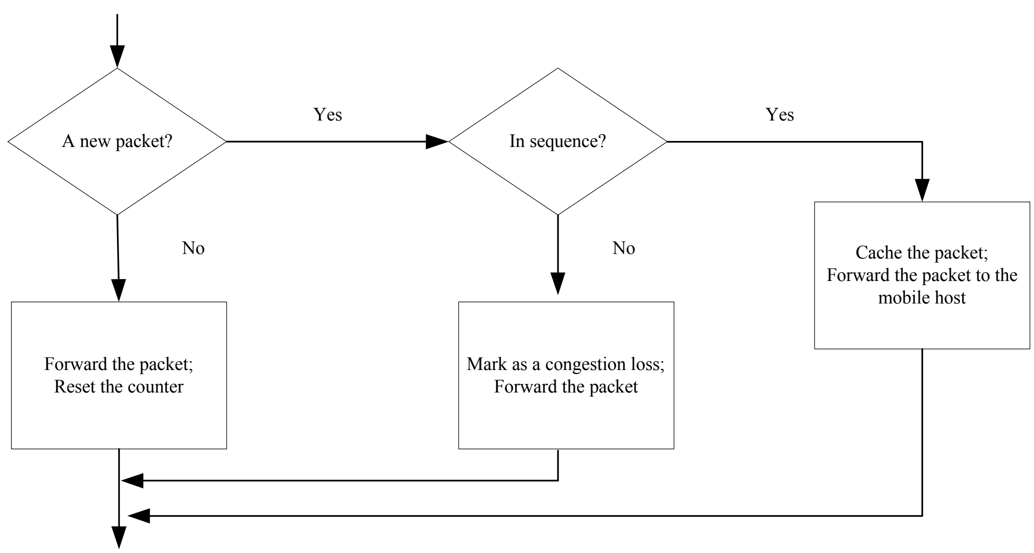

Figure 2. Access point/base station behavior upon receiving a packet from the fixed host

The local knowledge becomes a very important asset. For example, the data transfer from a mobile host to a fixed host (Figure 3) is based on this local knowledge that translates to a full control of both the base station and the mobile sender. The Snoop agent detects missing packets at the base station by (1) snooping on packets arriving from mobile host, and (2) identifying holes in the transmission stream. Based on local queue-length information, the agent using a heuristic classifies losses due to the wireless link into two categories. The first one is due to congestion, while the second category is due to a corruption. The corruption-induced losses are added to the list of holes. When there are duplicate ACKs for the ones marked in the holes and they arrive from the fixed receiver, then a bit is set in the TCP header of the loss packet and forwarded to the mobile sender. The sender uses the Explicit Loss Notification (ELN) bit to indicate a loss unrelated to congestion and then retransmits the packet without taking any congestion control actions.

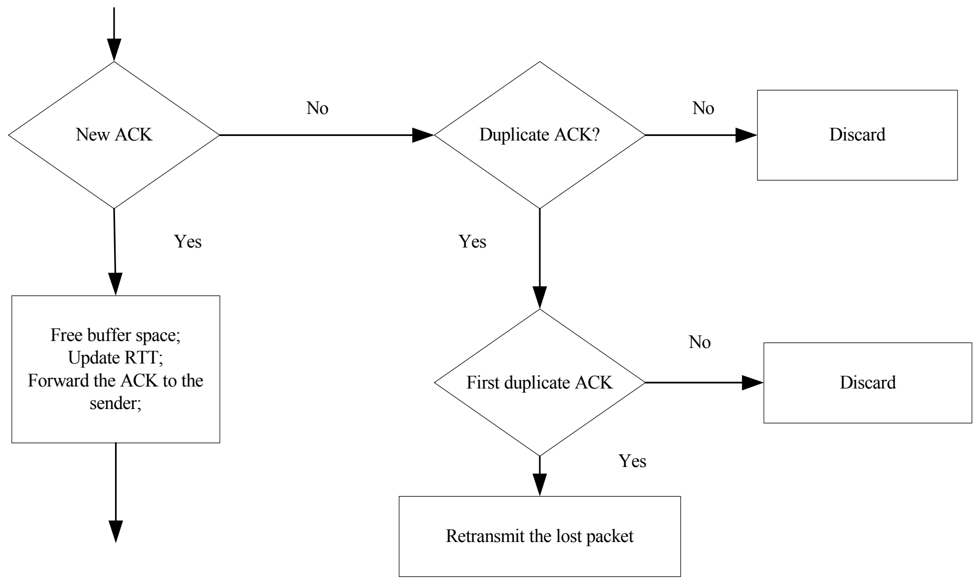

Figure 3. Access point/base station behavior upon receiving an ACK from a mobile host

3. VERIFICATION AND VALIDATION ISSUES

Formal methods combined with automatic verification and validation is the only reliable way to truly ascertain the correctness of an algorithm. The utility of this approach is becoming evident with the theory getting more sophisticated, the number of tools larger and the computational resources increasingly available. In the recent years, there have been a number of interesting and successful efforts to use these methods and tools in order to prove the correctness of and to validate some protocols pertinent to the different network layers. The PROMELA/SPIN model checking software suite, which allows simple and intuitive specification of distributed systems and performs model checking, has been most widely used.

The validation efforts are concentrated on the transport layer in the TCP/IP communication model. It is our intention to examine the applicability of SPIN for modelling the decreasing frequency of acknowledgments (ACKs) in relation to the congestion control in heterogeneous networks. In the modelling phase, one of the goals was to come up with PROMELA model of the protocol as close as possible to the original code of the state transition diagram [9]. While this may end up with less efficient PROMELA constructs, the confidence in the model makes up for possible inefficiencies. The derivation of the intended service by studying transition tables is an example of reverse engineering. Basically, if a protocol does not contain any obvious errors (e.g. deadlocks), then it should be validated against its service description [9], [10]. Otherwise, the absence of service description makes it rather difficult to identify properties that could be later checked with SPIN.

The following code describes the basics of the validation procedures:

(Modelling and validation in PROMELA) ≡

```
        (Start with abstract model)
        (Simulate and verify)
        while not (the model is acceptable)
        do
          if
                :: (Add details to model)
                :: (Introduce error into the environment)
                fi
                (Simulate and verify)
                od
```

One of the requirements for a protocol to be robust is to be able to deal correctly with errors in the environment. For example, errors in the underlying service will result in messages that may be lost in transit, or erroneous ordering of service primitives may lead to unspecified situations in the protocol and hence deadlock.

The procedure for the simulation and verification part is

(Simulate and verify)≡

***SIM**: **while not** simulation is acceptable)*

do

(simulate the model with spin)

if** (error found) **then

(correct error in the model)

goto SIM

fi

od

***while not** (verification is acceptable)*

do

(Verify the model with spin)

if** (errors found) **then

(Correct errors in the model)

goto SIM

fi

od

Whenever errors are found, they should be corrected and the simulation and verification step should start again.

4. CONCLUSION

The article presents the very first and rather rudimentary ideas about using formal methods and tools for modelling some of the problems on the transport layer (congestion management) in heterogeneous networks. The intention is to explore deficiencies in the TCP performance, TCP enhancements and agent-based mechanisms that eliminate them. The agent-based paradigm has shown as good as or better than end-to-end TCP modifications. The additional advantage is the possibility for rather fast deployment, which allows simple integration of wireless and mobile technologies in the global Internet.

The agent-based model, its behaviour and the corresponding protocols are subject to the verification and validation by using PROMELA/SPIN model checking suite. We believe that the combination of agent-based approach and the use of formal methods and tools will resolve some of the problems on the transport layer in heterogeneous networks, thus improving the overall traffic management which is the basis for the provision of QoS.

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