NETWORK AWARENESS SERVICE IN WIRELESS/MOBILE PERVASIVE COMPUTING IMPLEMENTATION OF A PIECEWISE APPROACH

ABSTRACT

Our paper considers a piecewise approach to network awareness service in wireless/mobile pervasive computing. As far as Pervasive computing is concerned it enables network devices to be aware of their surroundings and peers, and to be capable of effectively providing services to, and using services from, peers. The devices are made aware of the characteristics of the underlying network through Network Awareness Services (NAS). We have suggested a piecewise framework for the architecture by separating the wired elements from the wireless devices. A comparison has been made between the piecewise approach and the existing unitary approach and the analytical results have shown that the piecewise framework has significant advantages over traditional network-awareness frameworks in terms of reducing wireless bandwidth consumption and saving battery energy of mobile devices. The framework we have suggested is also scalable, i.e., it is suitable for a wide range of computing devices, from powerful ones with multitasking operating systems to small ones with light-weight OS.

CONTENTS

1. INTRODUCTION

1.1 PERVASIVE COMPUTING

"Anytime/Anywhere-->Any Device --> Any Network --> Any Data"

Pervasive computing can be defined as access to information and software applications anytime and anywhere. This form of computing is highly dynamic and disaggregated. It enables network devices to be aware of their surroundings and peers, and to be capable of providing services to, and using services from, peers.Pervasive computing increasingly involves mobile devices with wireless facilities. Only wireless/mobile devices with wireless Network Interface Cards (NIC) or wireless modems taking part in computing tasks with other fixed and wired devices are considered here.The generic architecture of the pervasive computing paradigm can be described from the figure shown below.

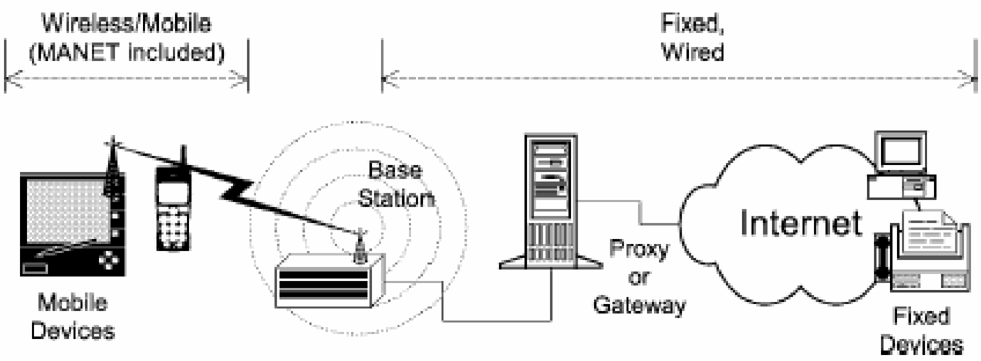

Figure 1. The generic architecture of wireless/mobile pervasive computing paradigm.

The figure shows two domains:

- ***The wireless/mobile domain*** connects to
- ***The fixed wired domain*** via a wireless link.

A dedicated proxy or gateway as a service point is generally used to enhance the performance of inter-domain communications.

There are three reasons for this:

- The amount of data transferred to mobile devices must be filtered because of the orders of magnitude difference in bandwidth between the wired and wireless connections.
- The wireless connection quality is too poor to sustain a client-server application.
- Portable computing devices have display and processing limitations that must be addressed by the proxy before sending the filtered response to the mobile devices.

1.2 NETWORK AWARENESS SERVICE (NAS)

To realize pervasive computing, network devices and applications need to be aware of network environments. Network Awareness is a key element in pervasive computing. Network awareness is the property of having knowledge about the current status of underlying network resources, but an important consideration should be that the cost of acquiring network awareness does not exceed its utility: if not obtained efficiently, it could decrease performance. Mobile devices are presented with some major challenges: network topology can change constantly, bandwidth can be limited, latency can be high and communication links can be down because of natural causes or power conservation. Hence, mobile agents need to be aware of relevant changes in the availability of network resources (awareness), and need to react accordingly to guarantee successful performance of their tasks (agility).

2. PIECEWISE DESIGN FOR NETWORK AWARENESS

Our approach to network awareness takes advantage of the fact that the generic architecture (shown in fig: 1) consists of a wired and a wireless part. Thus all issues related to awareness about an end-to-end communication link are considered piecewise, i.e., the wired and wireless parts are considered separately and the end-to-end characteristics are derived by combining the piecewise characteristics, whereas a *unitary* approach considers the entire communication path for the awareness purposes as a single piece. We expect the piecewise approach to enhance the performance of pervasive computing by saving the wireless bandwidth and battery energy and by reducing the inter-domain monitoring traffic for network awareness that is transmitted through wireless links. Moreover, piecewise network awareness, as a service, should be ubiquitously available in a pervasive computing environment.The NAS framework is designed to be scalable to both high-and low-power-computing platforms. Network awareness in this framework is piecewise and scalable to fit into the scenario of the pervasive computing paradigm with mobile devices of very low capabilities.

2.1 PIECEWISE FRAMEWORK ARCHITECTURE

The framework advertises the network awareness service. It acquires, measures, integrates, and distributes the parameters that reflect the current characteristics of the heterogeneous data networks. Network applications, protocols, and services that wish to use the NAS can acquire those parameters and apply them to leverage different pervasive computing tasks. The framework is transparent to network applications, services and protocols that do not explicitly use the NAS. It appears to them just as another network application.

The architecture of the NAS framework consists of four main components:

- The NAS Actor
- The NAS Database
- The NAS Administrator
- The NAS Agent.

Each piece realizes different functionality.

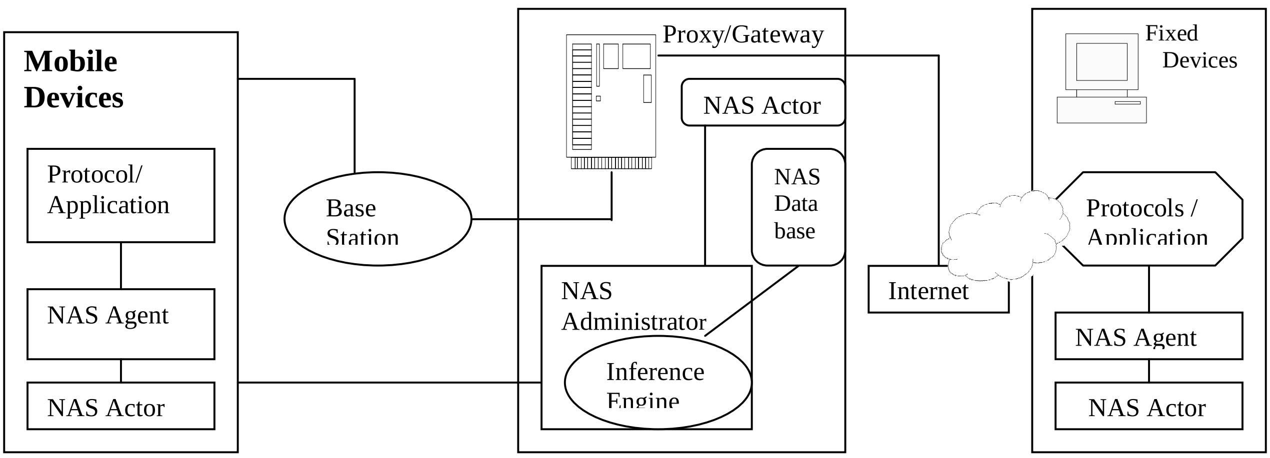

Figure2. Piecewise NAS Framework

2.1.1 NAS ACTOR

A NAS actor implements different network-awareness techniques, such as methods to obtain wireless-channel parameters or to measure the available bandwidth. It is an optional component at the mobile device, subject to resource limitations and the framework's scalability. Any network device with active NAS actors can be a service provider.

2.1.2 NAS DATABASE

The NAS database is a collection of data that reflect the current characteristics of the networks. Data are acquired from NAS actors at the proxy or gateway, collected from the NAS agents at mobile devices, integrated via an inference engine, and distributed by the NAS administrator. Some data may be selectively acquired from other service agents, such as SNMP agents and ICMP service. The database has a hierarchical architecture for simplicity, extensibility, and compatibility.

2.1.3 NAS ADMINISTRATOR

The NAS administrator manages the NAS database. It collects, integrates, and distributes the NAS data. The administrator may communicate with other service agents, such as an SNMP agent or SNMP administrator, to acquire additional information that the existing NAS actors do not provide and its inference engine integrates the data collected. Also, the administrator is responsible for answering queries from the NAS agent. Once the NAS administrator is activated at the proxy or gateway, it advertises NAS services through a well-known multicast channel defined in the NAS implementation (case 1 in figure 3). The advertisement includes the service name and description. The administrator also listens to the service advertisement and service subscription messages from NAS agents.

2.1.4 NAS AGENT

The NAS agent acts as an interface for the network devices which are interested in utilizing the services provided by the NAS framework. Based on the local device computing capabilities, the NAS agent will activate all the local NAS actors. Otherwise, the service actors are activated at the proxy or gateway. The agent informs the NAS administrator of the services provided by the active local actors. This is done through a well-known multicast channel.A protocol or application may approach the agent for services announced by the NAS administrator. If the information requested in the query can be obtained from local active NAS actors, the NAS agent will reply immediately otherwise, the NAS agent will redirect the query to the NAS administrator to perform the awareness task and return the reply.

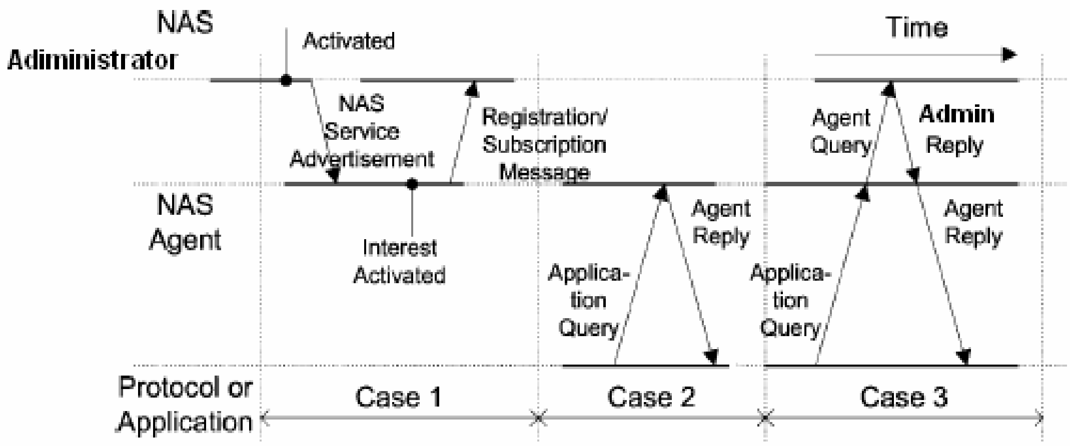

Figure 3. Communications between NAS components.

2.2 THE PUSH AND THE PULL MODELS

The push and pull models can be considered as a tradeoff between simplicity of implementation (pull model) and simplicity of use (push model). Mobility in pervasive computing imposes problems to both models. In the push model, the NAS may have difficulties tracking the roaming user through different networks. In the pull model, due to dynamically varying network performance, the application may not know when the time is appropriate to pull the information. The push model provides timely updates of information, but there are security and privacy concerns about the push model, since it may reveal the current status of a mobile user. For this reason, the pull model may be advantageous. The NAS framework supports both models.

3. PIECEWISENESS IN NETWORK AWARENESS TECHNIQUES

In traditional network awareness frameworks, awareness tasks are performed in a *unitary* fashion such that the entire communication path is considered as a single entity. For example, in the pervasive multimedia computing paradigm, where a mobile device needs to send its on-site video stream to a remote host located in an enterprise office, the mobile device first acquires the average available bandwidth of its inter-domain communication path to configure the resolution and frame-rate of the video stream. In unitary frameworks, the mobile device may send a number of back-to-back packet-pairs to the remote host, the remote host would bounce back the packet-pairs, and the mobile host would receive the packet-pairs and use the inter-packet time and packet-size to compute the available bandwidth.

Unlike a unitary framework, techniques in the piecewise NAS framework acquire end-to-end network awareness information in a piecewise way. The network awareness is considered in two parts: the awareness of the wireless/mobile domain and the awareness of the fixed wired domain. The NAS administrator or NAS agent integrates the intermediate results about these two domains and provides the final result to the application. Such a piecewise approach is expected to benefit service advertisement and discovery and network awareness by reducing wireless bandwidth consumption and saving battery energy of mobile devices. Here we present three examples of piecewise techniques for end-to-end NAS.

3.1 AVAILABLE BANDWIDTH:

The end-to-end available bandwidth is a frequently used parameter for adaptive applications. One method for available bandwidth awareness uses inter-packet time to estimate the characteristics of the bottleneck bandwidth link along the communication path. If two packets (e.g., ICMP probe packets) travel together, queued as pairs at the bottleneck link with no packet intervening between them, then their inter-packet spacing is proportional to the processing time required for the bottleneck link to transmit the second packet of the pair.

This inter-packet time method is made use of in the NAS framework. . The probing packets can be payload packets as well as explicit ICMP probe packets. When an application queries the NAS agent about the available bandwidth, the agent delegates the NAS administrator to perform this awareness task by sending a query with the address of the destination device. The administrator divides the task into three steps. First, it activates the NAS actor at the proxy/gateway responsible for the awareness service available bandwidth to measure the available bandwidth between the mobile device and the proxy, say, ***b1***. Next, it gets the available bandwidth between the proxy and the remote Internet device from the same awareness service by the NAS actor, say, ***b2***. Finally the administrator computes the end-to-end available bandwidth b as

$$\mathbf{b = min\ (b1,\ b2)}$$

and sends b as the result back to the NAS agent. Here, the first and the second step can be done in parallel. Finally, the NAS agent replies with the result to the application.

3.2 ROUND-TRIP TIME

Similar to the awareness of the available bandwidth, the NAS agent delegates the task of finding the Round Trip Time (RTT) to the NAS administrator. The RTTs are measured between the mobile device and the proxy/gateway, ***rtt1*** and between the proxy/gateway and the remote Internet device, ***rtt2***. The administrator computes the end-to-end roundtrip time, *rtt* as

$$\mathbf{rtt = rtt1+rtt2}$$

and sends *rtt* back to the NAS agent, which forwards it to the application.

3.3 PACKET LOSS TYPE

In the wired Internet, all losses are assumed to be congestion type losses (e.g., by TCP). In the pervasive computing paradigm, however, losses on wireless links occur frequently due to signal corruption or for reasons other than congestion, and such losses are called transmission losses. Congestion loss is a relatively sustained phenomenon compared to transmission loss. It is beneficial and sometimes essential for network applications to be aware of the different loss types, i.e., to differentiate between transmission losses and congestion losses. For example, since TCP assumes that all losses are of congestion-type, its performance degrades when temporary transmission losses are mistakenly considered as congestion losses, which unduly triggers TCP congestion control algorithms such as ‘slow start’ or ‘window decrease’. The piecewise NAS framework can be used to enable network applications at mobile devices to differentiate such losses. Packets of communication sessions are snooped by a NAS actor at the proxy/gateway. Once a network application at the mobile device observes a packet loss, it may query the NAS agent about whether the NAS also observed the same packet loss. If affirmative, then this packet loss is due to congestion loss, otherwise it is due to transmission loss. Thus the application is aware of the type of the packet loss and can react correctly.

4. BANDWIDTH-AWARE DATA STREAMING IN PERVASIVE MULTIMEDIA COMPUTING

An important application in wireless/mobile pervasive computing is tele-collaboration. For example, an on-site worker collaborates with an office-bound expert using multimedia application such as audio and video. It is important to improve the performance of the multimedia data streaming in this scenario. One approach is to use *bandwidth-aware* data streaming. For instance, a multimedia application learns about the average available bandwidth of its inter-domain communication path to configure its codec, e.g., the compression ratio and frame-rate. Here, the performance in terms of wireless bandwidth consumption will be compared between the piecewise and the unitary frameworks as they provide bandwidth awareness service to multimedia applications.

4.1 PERFORMANCE ANALYSIS

The end-to-end path of the multimedia data stream is between the mobile host and the remote host, i.e., an inter-domain communication path. Either of them could be the sender or the receiver. Assume that the path between the sender and the receiver is symmetric, meaning that the communication path characteristics are the same in both directions. In practice this is not true, though often the difference is small.

We denote the loss rate of the wireless/mobile domain as ***r1***, which is the probability of a packet being incorrectly transmitted / received between the mobile device nd the proxy/gateway. The loss rate of the fixed wired domain is ***r2***, which is the probability of a packet being incorrectly transmitted / received between the proxy/gateway and the remote host. Assume that ***r1*** and ***r2*** are constant and they are packet-independent.

$$p = (1 - r1)(1 - r2)$$

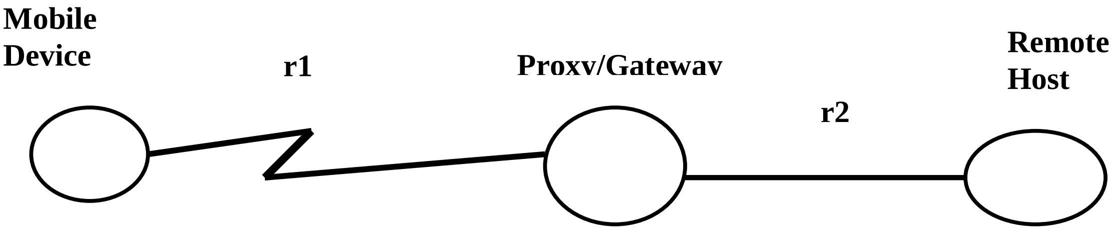

Figure 4 Performance analysis model for bandwidth awareness

The probability of a packet being successfully transmitted / received between the mobile device and the remote host is

$$\mathbf{p = (1 - r1)(1 - r2)}$$

According to the available bandwidth measurement algorithm, only when both packets in a back-to-back packet-pair travel a round trip successfully can a correct value of the available bandwidth be computed. For simplicity, assume that the query and the reply packets between the NAS agent and NAS administrator have the same size as that of the probe packet.

4.1.1 WIRELESS BANDWIDTH CONSUMPTION BY UNITARY FRAMEWORK

In a unitary framework, the available bandwidth is determined on the mobile device. The mobile device sends out the back-to- back probe packet-pair, receives the bounced packet pair from the remote host, and computes the available bandwidth. If only a single packet pair is used, the probability of obtaining a correct measurement is $\mathbf{p^4}$. If multiple, say M, packet-pairs are used, then the probability of obtaining a correct measurement increases, which is expressed as $\underline{1 - (1 - p^{4})^{M}}$

Therefore, to achieve the probability approximately equal to 1, M should be large. To achieve the probability β (99.99%) of successful service, at least Mt packet pairs should be sent, where

$$\mathbf{Mt = \log_{(1-p4)}(1 - \beta)}$$

because $\beta < 1 - (1 - p^4)^M$, if $p < 1$.

4.1.2 WIRELESS BANDWIDTH CONSUMPTION BY THE PIECEWISE FRAMEWORK

In the piecewise framework, the available bandwidth measurement in the fixed wired part does not consume the wireless bandwidth. Only the measurement in the mobile wireless part contributes to wireless bandwidth consumption. Based on the previous analysis, to achieve the same success probability β as for the unitary framework, at least Mp packet pairs should be used:

$$\mathbf{Mp = \log_{(1-q4)}(1 - \beta) + 0.5}$$

where $q = 1 - r1$. The 0.5 packet-pair comes from a query packet plus a reply packet between the NAS administrator and the NAS agent. Since $\mathbf{p < q}$, it follows that $\mathbf{Mt > Mp}$. Therefore the performance enhancement in terms of wireless bandwidth consumption is

(Mt − Mp)/Mp.

This can be substantial in the presence of unreliable communication as is the case in the Internet. An additional benefit of the performance enhancement is the battery energy saving, since the power amplifier of radio device draws a much greater amount of power during the transmission.

5. PLATFORM SCALABILITY OF *NAS* FRAMEWORK

5.1 UPWARD SCALING

As higher-performance and energy-efficient processors and memory chips emerge, more and more mobile devices will support multitasking operating systems. Thus multiple network applications can be active simultaneously at a mobile device. Suppose that the wireless link is the bandwidth bottleneck. In a unitary framework N applications are adaptive to the available bandwidth and perform the measurements independently. To achieve the probability (β) of successful awareness, the total wireless bandwidth consumption will be ***N* ×*Mt***, if there is no correlation among their individual measurement successes. In contrast, to achieve the same success probability β in the piecewise NAS framework, the total wireless bandwidth consumed will be only ***Mp***. An application sends the query to the NAS agent that delegates the task to the NAS administrator. The administrator obtains the value of the available bandwidth, b, from the NAS actor at the proxy/gateway, and feeds it back to the agent. Finally, the agent gets the traffic-multiplexing ratio, γ, of that application from the traffic scheduler, and replies with the final result, γ × b, to the application. Therefore, the other applications can share the measurement result b multiplied by their corresponding traffic-multiplexing ratios.

5.2 DOWNWARD SCALING

The minimum footprint of the NAS framework at the mobile device is the NAS agent, which is the service portal communicating with the NAS administrator. The NAS actors can all run at the NAS administrator's host. The agent is a simple proxy for invoking NAS administrator's services, thus making the framework downward scalable.

6. CONCLUSION

This paper presents a piecewise framework for network awareness service (NAS) for mobile pervasive computing. Piecewiseness in framework architecture and network awareness techniques in the NAS framework are investigated. Scalability of the framework is also discussed with regard to platform capabilities. The framework scales up to powerful computing devices with multi-tasking OS and scales down to small devices with lightweight OS. In pervasive multimedia computing, the bandwidth consumption is expected to be lesser on applying the piecewise NAS framework in contrast to the unitary network-awareness frameworks. Moreover, it is expected to reduce battery energy consumption of mobile devices.

REFERENCES