Vertical Handovers as Adaptation Methods in Pervasive Systems

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***Abstract*- Pervasive systems need to be context aware and need to adapt to context changes, including network disconnections and changes in network Quality of Service (QoS). Vertical handover (handover between heterogeneous networks) is one of possible adaptation methods. It allows users to roam freely between heterogeneous networks while maintaining continuity of their applications. This paper proposes a vertical handover approach suitable for multimedia applications in pervasive systems. It describes the adaptability decision making process which uses vertical handovers to support users mobility and provision of QoS suitable for users' applications. The process evaluates context information regarding user devices, user location, network environment, and user perceived QoS of applications.**

I. INTRODUCTION

The future generation mobile computing will provide users with a pervasive computing environment which offers seamless computing infrastructure and can intelligently support user tasks. The environment will use advances in high speed communication infrastructures (WLAN, GPRS, Bluetooth, UMTS, etc) and in sophisticated sensors and actuators. One of the requirements of seamless computing is network and device independence which allows users to move freely between heterogeneous networks and to change devices, if necessary, while maintaining application continuity. The issue which needs to be addressed in such pervasive environments is how to support multimedia streaming in an environment in which the context of computation may change, e.g. disconnections may occur or Quality of Service (QoS) provided by the network may change. The environment needs to be context aware and dynamically adapt to context changes. In the case of multimedia streaming the system may need to provide vertical handovers between heterogeneous networks as a response to context changes and also to adapt the communication stream to suit the new networking environment while providing QoS acceptable for users.

So far, research on vertical handovers has only concentrated on dealing with disconnections when users move out of a network coverage. The Daedalus project [2], developed a vertical handover mechanism for wireless overlay networks, where users were permitted to move in and out of a wireless network with minimal disruption to the application. The solution relied on mobile devices making handover decisions based on packet loss thresholds however this approach is not suitable for real-time applications like audio and video. The Full Stack Adaptation (FSA) [1] developed at the University of Florida allows vertical handovers between Ethernet, WLAN and WWAN. The architecture employed Mobile IP which leads to triangular routing [8], where all packets must be transmitted to the home network first before they are forwarded to the mobile's current network. This will increase latency to packets which may have fixed delay requirements. In both approaches the vertical handover is limited to disconnections resulting from user mobility. However, for pervasive systems, vertical handovers can be applied for a wider set of context changes. The following context changes should be taken into consideration in such systems: (i) users moving in or out of network coverage, or (ii) network QoS change which is unacceptable for applications, or (iii) users changing devices while continuing their applications (support for user independence from devices), or (iv) users entering preferred networks (support for user preference for communication networks).

In this paper we describe a solution for vertical handovers for multimedia applications in pervasive systems which addresses issues described in (i) – (iv). The solution is based on the assumption that pervasive systems have to be context aware in order to support mobile users, devices and applications under varying computing environment conditions, i.e. these systems manage context information and evaluate context changes to select appropriate adaptation methods. Vertical handover is one of such adaptation methods.

This paper concentrates on the handover decision making process which satisfies the four objectives mentioned above. This process has to evaluate context information (i.e. user devices and their capabilities, user personal context information, application QoS requirements and user perceptibility of application QoS, user location, network coverage and network QoS) to decide whether handover is necessary and whether additional adaptation needs to be applied. As it is difficult for users to describe communication QoS required by their applications using typical network terms (delay, jitter, packet loss) [3], the decision making process evaluates the user perceived QoS and provides a mapping from the user perceived QoS to network indices. The indices are used to make the handover decision. This allows users to specify their QoS requirements for multimedia applications in an understandable, user friendly form. The paper also briefly describes the QoS mapping between networks which is required for handovers and a mechanism employed to minimise QoS violations during handovers, however the detailed description of these two issues can be found in [4].

The structure of the paper is as follows. Section 2 describes the proposed vertical handover approach with the emphasis on the handover decision process. Section 3 describes both our prototype for vertical handovers of video streams and experimental results which demonstrate the decision making process in relation to user mobility and varying network QoS. Finally section 4 concludes the paper.

II. VERTICAL HANDOVER

The proposed handover redirects communication stream between different network interfaces on one device or between network interfaces on different devices for a variety of network technologies, including telecommunication networks (GPRS/UMTS). One of the main goals of the proposed solution is to minimise QoS violation for communication streams being handed over to other networks. The handover mechanism operates above the transport layer to allow changes between networks with different protocol stacks.

As shown in Fig.1, the architecture supporting vertical handovers includes the Context Repository which gathers and manages context information, the Adaptability Manager which makes decisions about adaptations to context changes (including decisions about handovers between networks), and Proxies which are responsible for executing handovers. Each network has its own proxy. A Domain Network Cluster (DNC) architecture is used, where multiple heterogeneous networks within a domain (eg. departmental, enterprise, etc.) are clustered together. As shown in Fig.1, each DNC is supported by the Adaptability Manager and the Context Repository. Components of the Adaptability Manager which provide the functionality described in this paper are also shown in Fig.1.

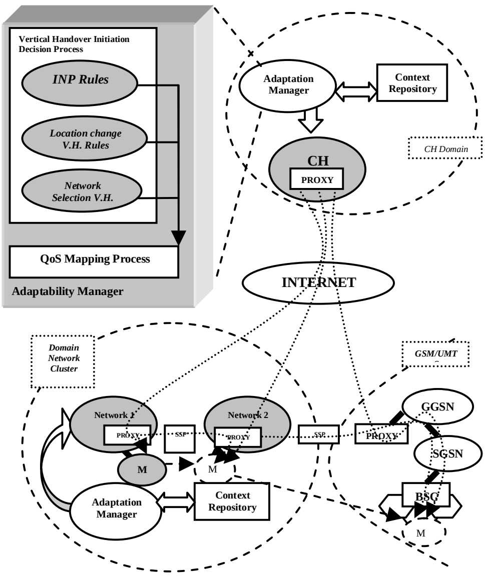

Fig. 1. Architecture supporting vertical handovers

A. Context Repository

The Context Repository provides a means to gather, manage and evaluate context information. The Adaptability Manager can subscribe to the Context Manager for notifications about particular context changes. In this paper we limit the description of context changes to this subset of context information which is needed to support vertical handovers. The context information used for vertical handovers is divided into static and dynamic profiles. The **static profile** holds information that does not change very often and includes description of devices, networks, applications and their QoS requirements.

The description of devices includes the list of *devices* belonging to a particular user as well as the *capability* description of each device. The device context also includes information about its network interfaces (the *networks* that are accessible from the device), and the *software applications* that may run on each device. Software applications are grouped into classes based on their communication requirements (Application Traffic Class Requirements – ATCR). The classes are as follows: Conventional Internet Services class (eg. web browsing, e-mail), Playback Streaming class (stored multimedia applications), and Conversational Streaming class (real-time multimedia applications).

The network context information includes potential network QoS and the *coverage* of the network. The latter is represented as a two dimensional *grid map*. The grid map also describes the transition zone of each network.

In addition, the static profile also includes the *user perceived QoS requirements* for multimedia applications, to allow users to express their perception of QoS for each ATCR. The user perceived QoS includes the video classification table (eg. temporality-slow, fast; detailing – high, low), type of video content, and the tolerable level of QoS (eg. overall video quality, disturbances, and bandwidth fluctuations permitted). The *personal setting* in the static profile allows user to define preferences for devices and networks. Since our architecture is able to provide vertical handover to GPRS/UMTS networks, the context information also needs to include the *User Cellular Network Profiles* (PDP context and QoS profile for each subscriber).

The **dynamic profile** holds the current information about users and networks such as the current user *location*, the current *QoS network parameters* (bandwidth, loss rate, delay, and jitter). The dynamic profile also holds information of the *Impending Network Profile (INP)* of the network to which the handover is most likely. This information changes dynamically when the user location or network QoS changes.

B. Adaptability Manager

The goal of the Adaptability Manager is to make decisions about handovers and to select adaptations for the communication stream, if necessary. Decisions are based on evaluation of context changes. The functionality of the Adaptability Manager can be divided, in the case of vertical handovers, into two main processes: ***Vertical Handover Decision Process*** and ***QoS Mapping Process***.

1)Vertical Handover Decision Process: This process decides when to invoke a vertical handover operation. The decision process evaluates (i) user location changes (as users may leave or enter a particular network coverage) and (ii) QoS of the current and alternative networks. The evaluation of user location changes is carried out based on the grid map of network coverage and considers location of users as well as device and network priorities. The vertical handover process is rule based and the rules are (informally) described further in this section. The QoS based network selection process is carried out to satisfy multiple objectives. The process is invoked when QoS of a particular network is below perceived acceptance quality, or a user enters the transition zone of a new network, or when determining the INP network. These objectives include satisfying the user's preferability of devices, achieving the highest level of bandwidth for their respective applications while minimising packet loss, delay, and jitter, and avoiding bandwidth fluctuations which may affect the applications. Our solution for this process is described below (following the decision rules).

Rule 1 (initialisation of applications or device change): For application intialisation, invoke the Locality based network selection process to determine the current device, current network and its INP network. In the event of device change, in addition, perform the vertical handover to new device (its INP network) then invoke Locality based Network selection process to determine a new INP network.

Rule 2 (moving out of current network coverage): If the user approaches the transition zone of the current network (is moving out of the network coverage), perform vertical handover to the INP network. Apply Locality based Network selection process to determine a new INP network.

***Rule 3 (entering coverage of new networks)*:** If the user enters a transition zone of a new network apply *Locality based Network selection process* to determine the network that can grant QoS which is closest to the application QoS requirements. If the network score is higher than current network, perform vertical handover and invoke *Locality based Network selection process* to determine new INP network.

Rule 4 (network QoS changes): In the event of a network QoS change, determine if QoS for the current network (expressed as the AHP score, see below) drops below the score of the INP network. If yes perform vertical handover to the INP network. Invoke *Locality based Network selection process* to determine new INP network.

Locality based network selection process: Select a set of networks for which the user can currently use (overlapping coverage), and from this set select a subset of networks for which there are user devices within a proximity of the user. On this subset of networks, perform the *QoS based network selection process* algorithm to determine the INP network.

QoS based network selection process. Selecting a network which meets user QoS requirements, requires satisfying the following four objectives:

Objective 1: Maximizing user device preferability.
Objective 2: Maximizing application bandwidth.
Objective 3: Minimizing jitter, delay, and loss.
Objective 4: Minimizing bandwidth fluctuations.

Since a number of objectives must be satisfied, the Analytic Hierarchy Process (AHP) [5] method is employed. The AHP is a decision support tool which uses multi-level hierarchical structure of objectives and criteria. The AHP method was chosen due to its ability to vary its weighting between each objective, which fits well with our requirements that the decision making process applies user perceived QoS and the result of the process is different for every individual profile.

The AHP calculation is a three step process:

Step 1-Calculate the objective weights from the objective pairwise comparison matrix (equation 1) based on *user QoS perceptibility* and the *personal setting* context (through relative values (RV)).

$$A = \begin{array}{c} \\ obj_1 \\ obj_2 \\ obj_3 \\ obj_4 \end{array} \begin{array}{c} \begin{array}{cccc} obj_1 & obj_2 & obj_3 & obj_4 \end{array} \\ \begin{bmatrix} 1 & RV_{12} & RV_{13} & RV_{14} \\ \frac{1}{RV_{12}} & 1 & RV_{23} & RV_{24} \\ \frac{1}{RV_{13}} & \frac{1}{RV_{23}} & 1 & RV_{34} \\ \frac{1}{RV_{14}} & \frac{1}{RV_{24}} & \frac{1}{RV_{34}} & 1 \end{bmatrix} \end{array} \quad (1) \qquad A_{norm} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \quad (2)$$

The RV value determines the relative weight involved in each criterion, where an element R_{ij} indicates how much more important objective i is than objective j [5]. This process systematically applies weights on each objective relative to the importance of other objectives. For example, RV_{12} expresses the relative ratio of user device preferability (objective 1) and video quality (objective 2). Based on the context information provided in Fig.3, where a score of 1 is set for user device preferability and 5 for video quality, the ratio is 1/5=0.2. Calculating the linear score, RV_{12}=(1-0.2) x 10 = 8 (a score of 8 shows a large separation gap this user has chosen between objective 1 and 2). Similarly, RV_{23} which expresses relative ratio of video quality (objective 2) and overall disturbances (objective 3), is calculated based on a score of 5 for video quality and 3 for overall disturbances, giving the ratio of 3/5=0.6. The linear score, RV_{23}=(1-0.6)x10=4 shows a fairly small gap between the two objectives. Matrix A is then normalized (equation 2), where the average values (a_{ij}) of each row for objective i is calculated (equation 3)

$$w_i = \frac{a_{i1} + a_{i2} + a_{i3} + a_{i4}}{4} \qquad (3)$$

to give the weights for each objective (w_1, w_2,,w_3,w_4).

Step 2 -Calculate the network scoring with respect to each objective through the network pairwise comparison matrix (equation 4).

$$\begin{array}{c} \\ Network_1 \\ Network_2 \end{array} \begin{array}{c} \begin{array}{cc} Network_1 & Network_2 \end{array} \\ \begin{bmatrix} 1 & RV_1 \\ \frac{1}{RV_1} & 1 \end{bmatrix} \end{array} \quad (4) \qquad \begin{bmatrix} 1 & 6 \\ \frac{1}{6} & 1 \end{bmatrix} \quad (5)$$

The purpose of this step is to determine the importance of each objective towards each corresponding network, unlike step 1 which concentrated on the importance of each objective towards the user. For each objective, a different scoring technique is applied to assist in efficient network scoring. For objective 3, a QoS space is employed to determine in which region, the QoS parameters (jitter, delay, and loss) lie.

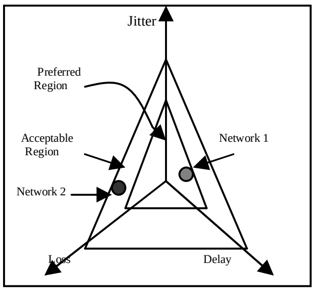

Fig.2. QoS Space scoring criteria for objective 1

As shown in Fig.2, the effective QoS space is separated into two regions, which are the preferred region and the acceptable region, with the optimum QoS being the origin vertex of the graph. The acceptable and the preferred regions are defined by the bounded limits for each parameter. The relative score is only apparent if two QoS network parameters are in different regions (as shown in the diagram), where a score of 4.5 is allocated to the less preferable network. Objective 4 (equation 6) and objective 2 (equation 7) rely on the relative ratio difference, where the ratio is then linearly scaled between 1-9 to obtain the score. The autocorrelation of the bandwidth samples are used to determine the degree of fluctuation for objective 4.

$$Relative\ ratio_{Bandwidth\ Fluc} = \frac{Autocorrelation_{Network\ 1}}{Autocorrelation_{Network\ 2}} \qquad (6)$$

$$Relative\ ratio_{Network\ Bandwidth} = \frac{Network\ Bandwidth_{Network\ 1}}{Network\ Bandwidth_{Network\ 2}} \qquad (7)$$

For device preferability (objective 1), the relative score is calculated from the differences in priority and scaled between 1-9. For example, to calculate the score value for a user who has devices as described in Fig. 3 including PC device (priority 1) and Phone (priority 3), the difference in priority=2 and scaling between 1-9 gives a score of 6 (again a fairly large gap between the network preferability), which results in a pairwise matrix shown in equation 5. This calculation is performed for all objectives to determine the score for each network. Similarly to step 1, after normalizing equation 5, the average values of each row is calculated to obtain a score for each network of the corresponding objective – $S_{i1}, S_{i2}, \ldots S_{ij}$ (objective j, network i). In this case $Network_{1obj1} = 0.84$ and $Network_{2obj1}=0.16$.

Step 3-Determine the sum of products of weights and network score for each network obtained from step 1 and 2 (equation 8), and select the network with the highest sum.

$$Overall\ score_{Network_i} = \sum_1^n S_{ij}(w_j) \qquad (8)$$

For the AHP calculation, **Step 1** is performed only once, whereas **Steps 2** and **3** are performed every time the *QoS based network selection process* is applied.

*2)**The QoS mapping process**:* When a decision is made that a handover should be performed and to which network, the QoS mapping process is required to adapt the communication stream to suit both the new networking environment and the new device capability (the latter only in the event of the device change). Our QoS Mapping process deals with the availability of network resources (bandwidth) and if necessary it selects an appropriate stream conversion and filtration to suit bandwidth availability in the new network. Using context information about the device input frame rate and network bandwidth, QoS mapping process determines the degree of filtering required on the communication stream. The filters are applied at the proxies residing in each of the networks, which are described in the next section. The QoS mapping is extended if the user moves on to a GPRS/UMTS network, to incorporate the QoS profile context subscribed by the user.

C. Network Proxies

The proxies residing in each network are used to redirect communication streams between networks during vertical handovers. The proxies receive notification of requested handover operations from the Adaptability Manager. Since our architecture provides vertical handovers to GPRS/UMTS networks, a proxy is also placed at the interface of the GPRS gateway node (as shown in Fig.1).

The proxies provide QoS support during the handover through two operations: doublecasting the stream during handovers and dynamic packet buffering. The doublecasting operation performed by the proxy sends the stream to the mobile host and also to the new proxy the mobile host is migrating to. This operation is shown in Fig. 1. Initially the mobile host is connected to Network 1. Packet stream is transmitted through the proxy of the Correspondent Host and streamed through the proxy of Network 1 to the mobile host. When a vertical handover is triggered, the stream is also sent from the proxy of Network 1 to the proxy of Network 2. As the mobile migrates to Network 2 the packets are continuously streamed to the mobile host through the new proxy. During this operation, the stream is redirected from the Correspondent Host to Network 2. As soon as the redirected packets arrive, the doublecasting operation is terminated. The purpose of this operation is to eliminate packet losses during vertical handovers, and minimise delay and jitter. It is also supported by the dynamic buffering mechanism which buffers packets during the handover to avoid any packet losses and eliminate any jitters that are imposed on the packet streams. The detailed description of this mechanism and its justification is presented in [4].

III. PROTOTYPE AND EXPERIMENTS

A prototype has been built which demonstrates vertical handover for a streaming JPEG RTP video application using the Java Media Framework (JMF). The proxies situated in each network were built from the JMF components. The scenario depicted for the prototype is shown in Fig. 3 (static and dynamic context information) and Fig.4 (grid map). The static context profile shows user devices and their ranking. Only part of the dynamic context profile is presented showing the current device, current network and the INP network.

For this particular application, the objective weights were calculated from the user perceived QoS (step 1 AHP calculation) which resulted in the following values: $w_{obj1}=0.445$, $w_{obj2}=0.05$, $w_{obj3}=0.1$, and $w_{obj4}=0.445$. According to these objective weights, large weights were applied to objective 1 & 4, followed by objective 3 and lastly objective 2.

Location changes are illustrated in Fig.4, and the results of the network QoS monitoring are presented in Fig. 7, 8, 9, and 10 (bandwidth, delay, jitter, and loss respectively). To make the solution scalable, notifications about users entering/leaving network coverage and about QoS changes are delivered to the Context Repository by the location/QoS monitoring agents. The Adaptability Manager evaluates these changes (based on Rules 1-4) to make a decision about vertical handovers. However, for the purpose of this prototype, to better illustrate the evaluation process, a continuos QoS based network selection was used as described below.

The grid map illustrates the transition zones for the WLAN and Ethernet networks for the PC and Laptop. In this scenario, the user was using a laptop and was connected via Ethernet at position (7,9). Based on this position and the current device, the INP network is set to WLAN (Rule 1). According to Fig. 5, the average bandwidth availability on Ethernet network was 494.3 KB/s, therefore the level of filtering for the stream was set to 0.1 (level of filtering is between 0.1-0.9 for bandwidth between 413KB/s to 1.3MB/s) to provide a JPEG RTP stream at an average of 413 KB/s as shown in Fig.5. Before time 13, the bandwidth fluctuations on the Laptop-Ethernet was slightly higher than for the WLAN network (where the highest objective weight is applied – objective 4), while at the same time monitored jitter, delay, and loss showed a relatively linear decline. The calculated score for the user current network and INP network (equation 8) is shown in Fig. 6. The Network score graph shows the relation of the scores compared to the current bandwidth, jitter, delay and loss.

At approximately time 12, the current network score (score – 0.413) dropped below the score of the INP network (score – 0.586), requiring the Adaptability Manager to perform a vertical handover from Ethernet to WLAN on the same device (Rule 4). The proxy of Ethernet network performs a doublecasting operation to the proxy of WLAN network, during which packets are redirected from the correspondent host to the WLAN proxy. The time for vertical handover is determined by the amount of time it takes for the packets of the new stream to arrive at the mobile. The time for stream from Ethernet proxy to reach the mobile amounted to *20ms*, while the vertical handover time for the new stream from the correspondent host to the mobile was approximately *30ms*. A QoS mapping operation was performed to determine the new stream bit rate. According to Fig.7, the average bit rate on WLAN network is 965KB/s. The Adaptability Manager therefore upgrades the filtering level to 0.6 resulting in a higher quality stream of 777.67 KB/s, which can be seen in Fig.5 as the average arrival rate increases.

Static Profile
*Device Preferability and Ranking
1. PC(Ethernet) - Input Bit Rate – 1MB/s
2. Laptop (Ethernet, WLAN)-Input Bit Rate –1MB/s
3. PC (Home) -Input Bit Rate – 1MB/s
4. GPRS/WAP Phone-Input Bit Rate – 150KB/s

*User Perceptibility Input
1. Current Application : ATCR 2: Slow moving, not fine, documentary
2. User devices preferability - 1
2. Video Quality – 5
3. Fluctuation of video quality – 1
4. Overall Disturbance – 3

Dynamic Profile
Current device – Laptop
Current Network – Ethernet; INP Network - WLAN

Fig.3 Context scenario

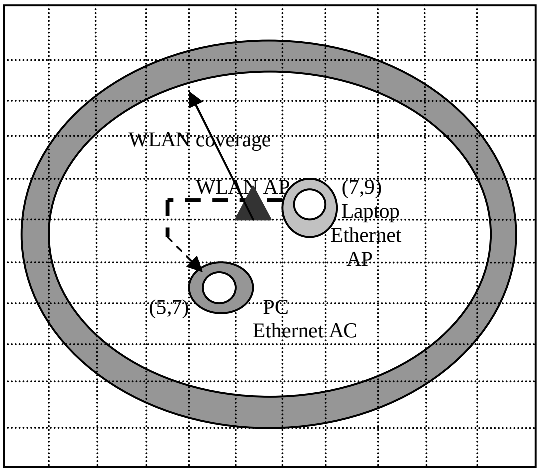

Fig.4. Grid map for prototype scenario

Immediately following vertical handover, a new INP network is calculated based on the *Locality based network selection process* and is set to Ethernet. However, at time 13 the user moves away from the Ethernet access point and the INP network changes to GPRS. This change of INP is evident from the graph at time 13, where a large variation gap is shown between the WLAN and GPRS network. This gap is due mainly to QoS characteristics of the GPRS network which shows the average delay, loss, and jitter being relatively high compared to WLAN and at the same time a lower bandwidth availability from the GPRS network.

The user changes location at time 16 and moves along the path shown in the grid map. At location (5,7) a notification arrives that the user entered the transition zone of the new network. At this location, the user enters a new network zone with a new device, which is a PC connected to the Ethernet network. The Adaptability Manager performs the AHP calculation (Rule 3) to determine if the new network can offer better resources with respect to the user's perceived QoS. This is shown in Fig. 6, at time 22, where the current network is set to PC-Ethernet (score – 0.53) and the INP network is set to Laptop-WLAN (score – 0.375) with the network score favoring the PC Ethernet. Fig. 7 shows the bandwidth of the Ethernet network to be reasonably close to the WLAN, and therefore the communication stream does not require any further adaptation. The vertical handover time between the Laptop-WLAN to PC-Ethernet was negligent, due to the fact that doublecasting is performed to the two devices during the vertical handover, before the Adaptability Manager terminates the stream to Laptop-WLAN. Therefore, the user will receive the streaming on both devices for a small period of time, before the Adaptability Manager terminates the communication stream to the Laptop-WLAN.

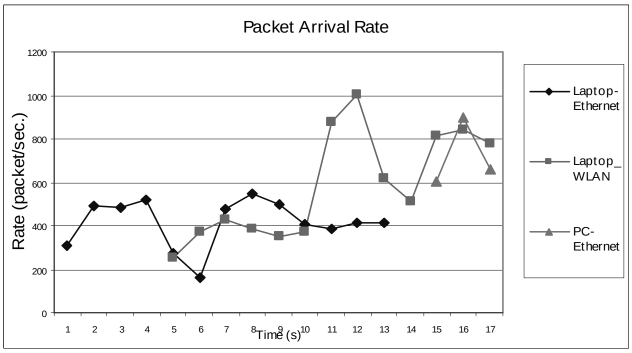

Fig.5. Packet arrival rate

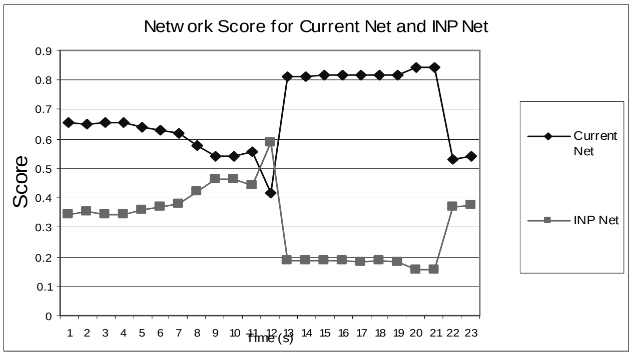

Fig.6. Current Net and INP net current score

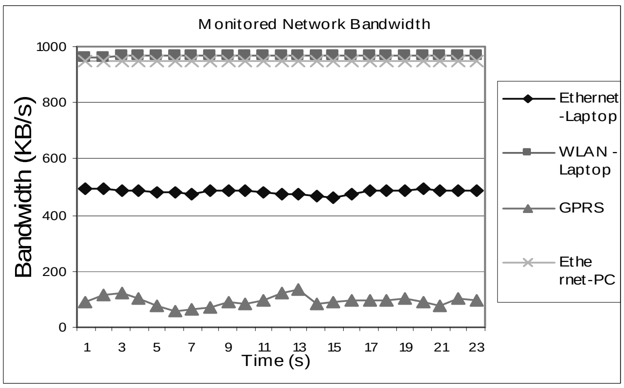

Fig. 7. Monitored bandwidth of accessible networks

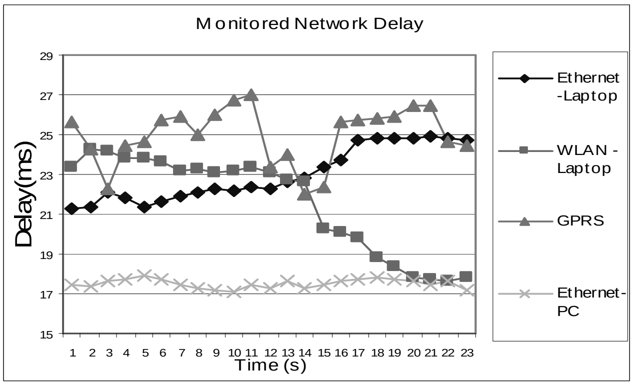

Fig.8. Monitored packet delays

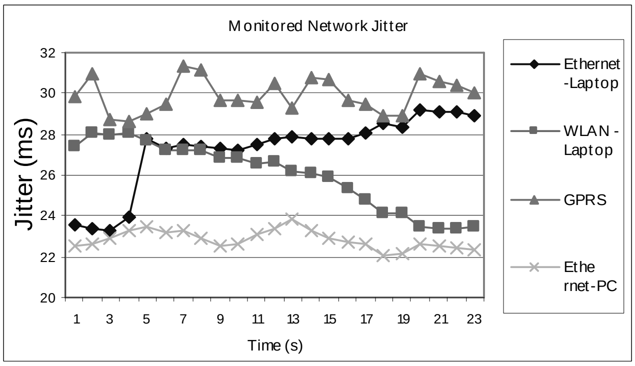

Fig.9 Monitored packet jitter

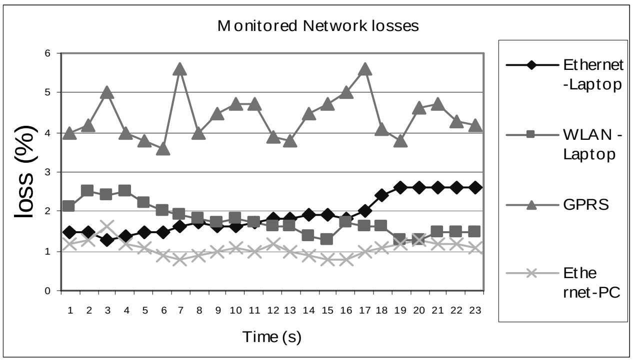

Fig.10. Monitored packet losses

IV. CONCLUSION

We have presented in this paper a context-aware vertical handover that is built for future pervasive environments. It can be used as one of adaptation methods to context changes in such environments. The proposed vertical handover operates above the transport layer and its architecture includes a context repository for gathering context and monitoring context changes. Context changes are then evaluated by the Adaptability Manager. To provide the required functionality, the Adaptability Manager employs two processes: the Vertical Handover Decision Process and the QoS Mapping Process. The Vertical Handover Decision Process applies rules when evaluating notifications about location and QoS changes. The AHP algorithm is used to select a network which provides the closest match with application QoS requirements. AHP utilises the user perceived QoS as ordinary users are not able to express communication QoS requirements in terms of network indices. The QoS mapping process adapts the communication stream to the new network and/or device if necessary.

A prototype handover architecture has been developed for JPEG RTP video transmission. Experimental results of the evaluation of context changes and the AHP calculation to select a new network have been presented. The AHP calculation shows the varying network scores for network evaluations as time changes. The vertical handover times are short due to applied doublecasting between proxies of the old and a new network. The proposed vertical handover mechanism is currently being integrated with our infrastructure for pervasive computing [6,7].

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