Supporting Adaptive Real-time Mobile Communication with Multilayer Context Awareness

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Abstract Real time mobile communication is challenging due to the inherent limitations of mobile networks. On the other hand the stringent quality of service requirements of real time traffic is highly in demand. Our first contribution is the generic context aware architecture for adaptive real time applications. Adaptation is based on the awareness of context parameters from different layers of the existing protocol stack which involves context exchange among the neighboring layers as well as non-neighboring layers. The architecture comprises of context representation, context acquisition, cross-layer context exchange and context management. Our second contribution is the mobility aware, adaptive Multi-homed Mobile IP. Simulation of adaptive M-MIP was carried out as a proof of concept. Simulation demonstrated that adaptation to mobility was able to decrease Mobile IP handover latency. Further, the results show that the quality of service of real time traffic can be enhanced by using context aware adaptive MIP. The simulation involved with various speeds ranging from pedestrian scenarios to vehicular scenarios. Results are analyzed with variable data rates. The evaluations show that performance of the proposed solution is better compared to conventional MIP in terms of packet loss and throughput of real time traffic.

1 Introduction

Layer standardization is vital as the foundation of internetworking computers. It is still applied and functions efficiently in static wired networks. It enables standardization of the system design and implementation hence reduces design complexity. Moreover, the layered approach assures interoperability between different systems and ease maintenance because of modularity. By maintaining layers independent of the others, controlled interaction among them can be guaranteed.

Though strict layered approach functioned as an elegant solution for internetworking static wired networks, it is not adequate for efficient functionality of wireless networks. Inherent broadcast nature of wireless medium and interdepen-

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dency between overlapping connectivity pairs restrict the efficiency of media applications. Moreover, the dynamic nature of network topology due to random movements of nodes adds extra complexity. Further, there are stringent resource constraints in wireless networks in terms bandwidth, energy and available battery power and computation capabilities of hosts. Utilization of network bandwidth and other limited resources have to be managed efficiently. The long distance communication is forced through multi-hop. Routing is complicated and needs interaction among other applications.

The applications should be managed and adapted to dynamic nature to improve performance. Especially resource hungry applications like real-time media should be managed dynamically. Moreover, next generation situation and context aware applications necessitate the adaptation. This adaptation may range from application adaptation to channel adaptation. In application adaptation, running applications adapt to the lower layer conditions such as dynamic network conditions. In channel or lower layer adaptations, lower layer entities or protocols adapt to meet application quality of service requirements. Cross layer interaction was proposed in the literature as a solution to avoid bottlenecks of the strict layered protocol design in wireless networks. On the other hand there are some controversial arguments about cross layer interactions in wireless networks [4]. Kawadia and Kumar [4] argue that once the layers are broken through cross layer interactions, it affects not only to the layer concerned but also to the other parts of the system. Moreover, they discuss the fact that cross-layer design causes several adaptation loops which are parts of different protocols interacting with each other. Finally, [4] was concluded with the fact that cross layer interaction should be exercised with appropriate caution. This raises the research challenge of designing cross layer interactions without complete redesign and replacement of the system, without unintended interactions and with carefully examined dependency relationships.

We argue that the existing strict layered architecture itself is not sufficient to support the next generation context aware, adaptive wireless communications due above discussed facts. On the other hand we agree to the fact that full cross layering by loose coupling of protocol stack destroy the concept of modularity and hence the interoperability of various systems. We propose that cross layering should be used without breaking the modularity of the protocol stack to balance these two extremities. We believe that cross layer interaction is still a promising paradigm for wireless networks if it is carefully and appropriately designed. Furthermore, we present the argument that cross layer architecture should be designed using proper design considerations to ensure the generality, modularity, maintainability and efficient operation.

Section 2 of this paper analyses the related work. Section 3 presents our cross layer context aware architecture, which is called Context Aware Architecture for Adaptive Real-time Mobile Communications (CA3RM-com). Section 4 discusses the evaluation of a scenario in the simulation setup. The simulation scenarios, topologies control variables of the simulation and results analysis is presented in this section. Finally section 5 concludes the paper.

2 Background

There were different cross layer architectures proposed in the past. Some proposed frameworks or architectures tailored towards specific requirements, which are non-generic in design goals. We consider, only the architectures, which are based on a generic design in this section.

Wang and Rgheff [12] suggest a mechanism called CLASS for direct signaling between non-neighboring layers. Internal message format of CLASS is light-weighted, but the external information flow is based on standard ICMP and TCP/IP headers so external messaging is not flexible and not synchronized with the internal messaging format proposed in CLASS. CLASS proposal violates the concept of layered protocol stack by direct signaling among layers for performance objectives.

Cross layer architecture in MobileMan [6] project adds another stack component called network status which is accessible by each layer. They recommend existing stack replacing the standard protocol layer, with a redesigned network-status-oriented protocol, so that the protocol can interact with network status. This design supports the local and global adaptation to all network functions through the network status. Authors mention that non-cross layer optimized protocols can still function within the framework they propose. But this framework can't be equally applied for protocols which are not network-status-oriented. Even for network-status-oriented protocols there is a need of redesigning.

The GRACE (Global Resource Adaptation through CoopEration) project [9] considers four different layers which are the network layer, the application layer, the hardware layer, and the operating system layer all connected through a resource manager. GRACE differentiates between two kinds of adaptations, global and local. The admission process and resource reservation process is costly for new applications entering in to the system. Further, global adaptation they defined requires hardware and software reconfiguration which is a bottleneck.

CrossTalk [8] is a cross-layer architecture in which locally available information is used to influence protocol behavior, and it also establishes a global view of the network according to one or multiple metrics like energy level, communication load or neighbor degree. The CrossTalk architecture consists of two data management entities. One entity is for the organization of locally available information. The other data-management entity is for network wide global view. To produce the global view, CrossTalk provides a data dissemination procedure. Establishing a global view and data dissemination is costly and complex. Application of CrossTalk to individual protocol requirements, for instance adaptation to mobility is not obtainable. Information in relation to whether CrossTalk handles conflicting global or local optimizations which may lead to overall system performance degradation is not presented.

In ECLAIR [11] a tuning layer (TL) for each layer, provides an interface to read and update the protocol data-structures. TLs are used by Protocol Optimizers

(POs), which contain cross-layer feedback algorithms. It is based on registering and notification process. ECLAIR doesn't support global context and adaptation. This solution mainly discusses the optimization or context manipulation in a particular protocol. For the proposed system to work the protocols and applications should have the strict structural differentiation that the ECLAIR solution is based on. Moreover the protocol optimization functionalities are carried out in individual performance optimizers, in which there is no central control. This could lead to conflicting optimizations and hence ultimate system performance degradation.

3 CA3RM-Com Architecture

3.1 Design Considerations

CA3RM-com is the context aware architecture we propose, which facilitates the context aware adaptation. The architectural is based on several design goals.

CA3RM-com is generic and can facilitate context aware adaptation for any protocol or application in the protocol stack. This architecture is not specifically tailored to a particular adaptation or application domain. Any entity in a layer of the protocol stack can subscribe to the LAYER LENA of ConEx [5] to request context. Since it is generic it can be used and extended in wide range of adaptations ranging from application adaptation to channel adaptation.

CA3RM-com attempts to achieve a balanced solution of performance benefits with a minimum and tight coupling in the protocol stack. Cross layer exchange can be achieved through subscriptions without changes to the existing stack. So, another important feature is the uninterrupted operation to the existing protocol stack for non cross layer functionalities. Interested protocols and applications can subscribe and register for context. CA3RM-com architecture can be easily and dynamically enabled/disabled.

CA3RM-com is an event driven system. Once a particular context is available in the system it is notified to entire set of interested entities who has subscribed. The architecture is based on event notifications to enable quick responsiveness to the events that are triggering. Context exchange in CA3RM-com is event driven rather than a context storing and querying system. It is an integral and important feature of a context aware adaptive system to ensure the delivery of most current context to the subscribers rather than obsolete context.

CA3RM-com architecture supports the context exchange within the mobile host which enables the local adaptation as well as global adaptation to the network wide contextual data [5]. Global context exchange is achieved through a specific node acts as the Global Event Notification Agent (GENA) in the network. GENA is the tentatively elected node in a situation of an ad hoc network. Internal and External messaging is synchronized. Another important feature in CA3RM-com architecture is the context delivery based on interest. Only interested protocols can subscribe to acquire the context in contrast to a context/message push system where the context is delivered to all the relevant entities.

CA3RM-com architecture facilitates flexible adaptation. It supports context awareness in three categories of adaptations. Protocols and applications can perform “Entity Executed” adaptations through either subscribing to context parameters or to adaptation itself. This way, interested entities can make individual functionalities efficient and adaptive through subscriptions. “System Executed” adaptations are used to force adaptations to achieve system performance. Moreover, the conflicting adaptations are handled in the system to avoid performance degradations that can cause by contradictory adaptations.

3.2 Modules of the Architecture

CA3RM-com architecture and its modules and components are shown in Fig 1.

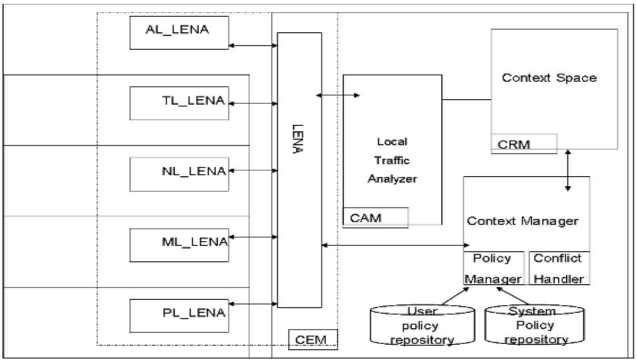

Fig 1. CA3Rm-Com Architecture.

Every context aware solution comprises of a mechanism to represent context, in this architecture it is called Context Representation Module (CRM). CA3Rm-Com architecture exploits extended version of Context Space [7] to represent context used for adaptive real time communication in mobile networks. Fig 2 shows the representation of context parameters and performance parameters in Euclidian vector space for a given problem domain. These set of parameters corresponds to a situation and represented by situation vector. Combination of context and performance parameters which form the context vector could be static and/or dynamic. Context vector corresponding to a given situation at time t v_t, can be represented as a vector consists of a set of context parameters (cp) and set of performance parameters (pp) as shown in Equation 1.

$$v_t = (\sum_{i=1}^{n} a_i cp_{xit} + \sum_{i=1}^{m} b_i pp_{it}) \quad (1)$$

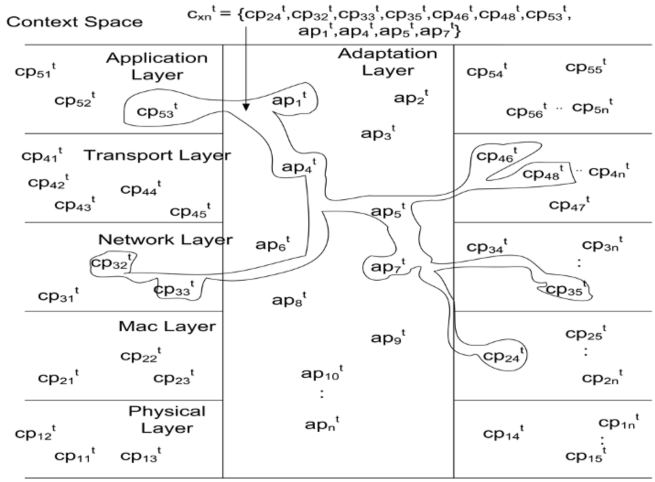

Fig 2. Context representation in context space.

Where, a_i, b_i are scalars. x indicates the layer number 1 to 5, which represent the indicate physical, mac, network, transport, and application layers of the practical protocol stack. cp_{xnt} is the nth adaptation parameter at layer x at time t.

pp_{nt} is the nth performance parameter at time t.

So, context vector at time t, can be written as shown in Equation 2.

$$v_t = (a_1.cp_{11t} + \ldots + a_n cp_{5nt} + b_1.pp_{1t} + \ldots + b_m pp_{mt}) \tag{2}$$

Context exchange across the protocol stack and the network is carried out through the Context Exchange Module (CEM) which is called ConEx [5]. ConEx is an event driven context exchange framework in which context delivery is based on subscriptions.

Context acquisition is accomplished through the Local Traffic Analyzer which sniffs the packets flow through the protocol stack. ConEx exchanges context via this Context Acquisition Module (CAM).

Context Management Module (CMM) executes two major tasks. Firstly Context Manager (CM) ensures that the context aware adaptations are based on predefined user and system policies through the Policy Manager (PM). Secondly CMM controls context aware adaptations to avoid unintended conflicts that may arise by uncontrolled adaptations. This is done through the Conflict Handler (CH).

Two main categories of adaptation are considered in the CA3RM-com architecture as illustrated in Fig 3. They are “Entity Executed” adaptations and “System Executed” adaptations. The term “entity” is referred to as any protocol or application throughout the discussion.

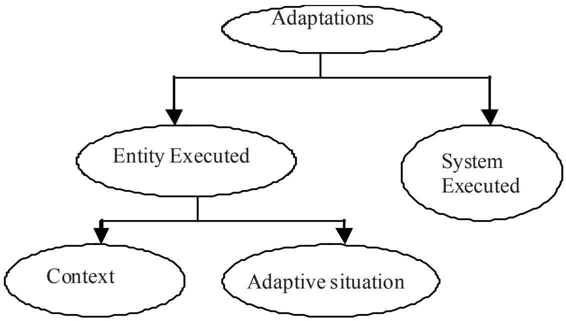

Fig 3. Categorization of adaptations supported.

In "Entity Executed" adaptations the entity which is interested in the adaptation subscribes to the architecture to execute adaptation. Entity executed adaptation can be achieved through two types of subscriptions. In one type of subscription, the entity requests particular context parameters in order to make the adaptation decision based on its own rules and conditions. In the other type of entity executed adaptation, entity make the subscription to an adaptive situation, where the policy manager executes the policies related to the adaptation and notifies the adaptation decision to the relevant entity. In "System Executed" adaptations, the entity is not involved in subscriptions but the context manager forces the adaptation to the entity based on system and user defined policies, which enable control and administration of the system.

4 Simulations

4.1 Scenario

A scenario is considered, where a traveling businessman engaged in a videoconference in his PDA at the office and is wandering around in the office buildings continuing the video conference he already initiated. It is essential to maintain uninterrupted ongoing session while moving from one network coverage area to another network coverage area. In this situation his mobility pattern could be predicted inside buildings and it could be unpredicted and random outside. This maintenance of the ongoing session is necessary with both the predicted and unpredicted mobility patterns. Moreover, the delay jitter, delay and packet loss should be minimized to achieve the quality of video conference. Later on, he would drive to his business site situated at another location. A situation is assumed where he travels by car, while continuing his business conferences. In this situation his mobility pattern is predicted on the road. As he crosses the intersections of highways the mobility pattern can become unpredicted.

In the scenario discussed above, there is a need of maintaining uninterrupted ongoing videoconference with guaranteed quality of service while moving. Mobile IP (MIP) is a promising network layer mobility management solution but its agent discovery and movement detection delays are significant for real-time data communication. The motivation of the simulation work is to minimize the handover latency in Mobile IP to cater for the quality of service requirements of real time applications depending on the situation awareness. Here we apply context aware adaptation to multi-homed mobile IP (M-MIP), based on this scenario. We discuss the simulation in detail in the section.

4.2 Evaluation

Context vector discussed in section 3 is used in context aware adaptive multi-homed mobile IP handover decision. Context parameters used were Constant Bit Rate (CBR) traffic at application layer, Relative Network Load (RNL) metric, frequency and Signal to Noise Ratio (SNR) of received Agent Advertisements (AA) in MIPV4 or Binding Updates (BU) in MIPV6, Round Trip Time (RTT) delay, jitter of BUs at network layer, radio receiver SNR threshold at mac sub layer. The performance parameters used in simulation were packet loss and throughput of CBR traffic.

The context aware adaptive MIP approach minimizes the overall handover latency by improving two phases of MIP layer-3 handover. The agent discovery / address configuration phase is improved by multi-homing. Movement detection phase was improved by proactive movement detection. Hence the total MIP handover latency is minimized by decreasing the agent discovery delay and movement detection delay. We use Multi-homed MIP [2] in evaluation. Gate Way (GW) selection based on RNL metric [1] is used, when ore than one candidate networks are available. In brief, If Mobile Node (MN) is multi-homed in an overlapping coverage area the RNL metric selects least congested GW as the default gateway. Agent advertisement frequency, RTT delay and jitter are used as context parameters. Proactive movement detection algorithm is based SNR of received Agent Advertisements (AA) in multi-homed MIPV4 or Binding Updates of multi-homed MIPV6. In addition to the SNR AA/BU at network layer, SNR threshold at mac sub layer are used as context parameters. This proactive move detection is beneficial over conventional unreachability detection in which the MN waits till AA/BU timeout. The detailed discussion of proactive move detection and its algorithms are beyond the scope of this paper.

The discussed scenario was simulated in a wireless set up. We present the simulation of the proposed solution which was carried out using the network simulator Glomosim [3] in this section. Agent advertisements in the MIP were sent every half a second and MN registers every third advertisement with the Home Agent (HA). Time out for bindings used was three times the agent advertisement time. Simulation was carried out for 200 seconds. CBR traffic flows were sent from MN to Corresponding Node (CN) every 3MS. Results for different data rates with different packet sizes were simulated. Scenarios of pedestrian speeds and vehicular speeds with varying data rates were simulated and the results are analyzed. Simulations of two approaches were examined to compare the performance of the proposed solution. Pure M-MIP approach, which does not use context exchange for handover decision is called WithOut ConEx (WOConEx) approach. SNR based movement predicted approach uses context for handover decision and is based on ConEx architecture hence referred to as the ConEx (ConEx) approach. Simulation was carried out for both approaches and results are compared. Results are presented as mean value of multiple simulations with different seeds to use normal distribution. Results are presented with 90% confidence level.

The network topology shown in Fig 4 was used to simulate various moving speeds of the MN. Results of two major speed categories were examined and analyzed. One is the pedestrian speeds. The other simulation was carried out to represent a vehicular network, where mobile node was moved with vehicular speeds.

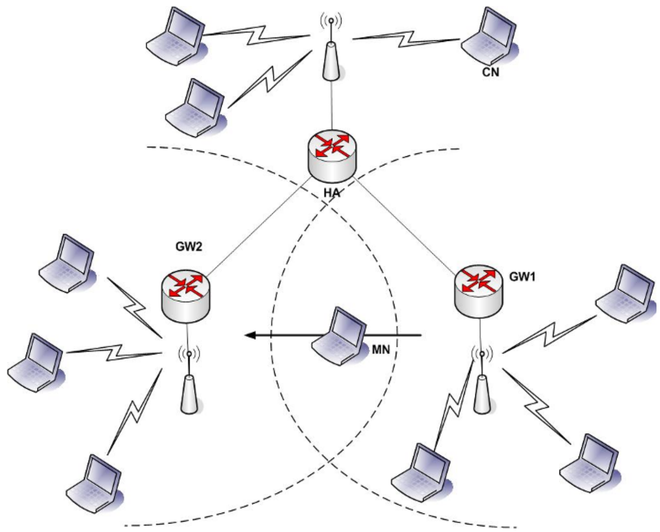

Fig 4. Network topology used in speed analysis.

Fig 5 and Fig 6 represent the results of simulations carried out in situations where MN moves in walking speed. The speeds tested are from 2m/s to 4 m/s. 2m/s represented as MP1_S2, 3m/s represented as MP1_S3, and 4m/s represented as MP1_S4 in the graphs.

Fig 5 shows the packet loss rate of CBR traffic for variable mobility speeds in the range of walking speeds. In the “WOConEx” approach, there is a delay for move detection since the MN waits till agent advertisement timeouts or registration timeouts. Due to the delay of move detection in “WOConEx” a considerable packet loss is noticed. In “ConEx” the move detection delay is zero since the movement is detected before loosing the current network attachment. So the packet loss rate is zero in "ConEx". The graph in Fig 6 shows the throughput of CBR traffic for variable data rates where the mobility speed is in the range on walking speed. Due to the packet loss during the handover in this approach, the throughput is lower. There is a significant decrease in throughput as the speed increases.

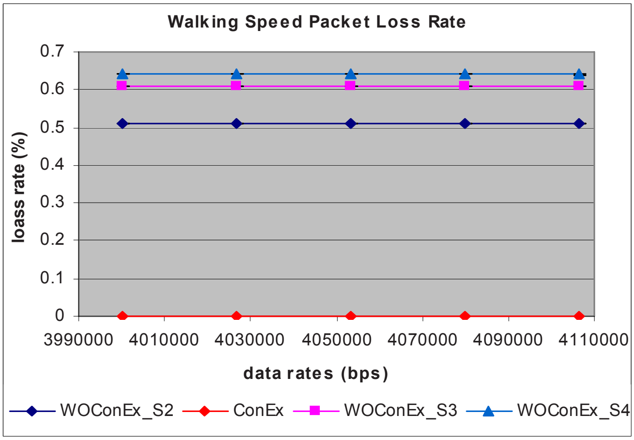

Fig 5. Walking Speed Packet Loss Rates Analysis.

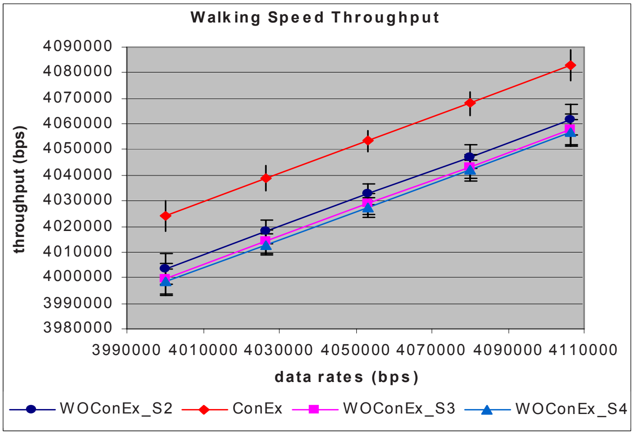

Fig 6. Walking Speed Throughput Analysis

The graphs in Fig 7 and Fig 8 show the packet loss rate and throughput of CBR traffic for variable mobility speeds in the range of vehicular speeds. Explanation of reason for increased packet loss and decreased throughput at higher speeds of WOConEx and the way it was avoided in ConEx solution are similar to the explanation discussed in the sub section of walking speeds.

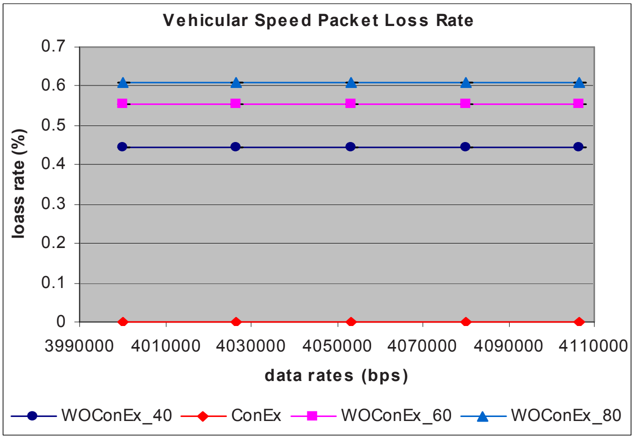

Fig 7. Walking Speed Packet Loss Rates Analysis

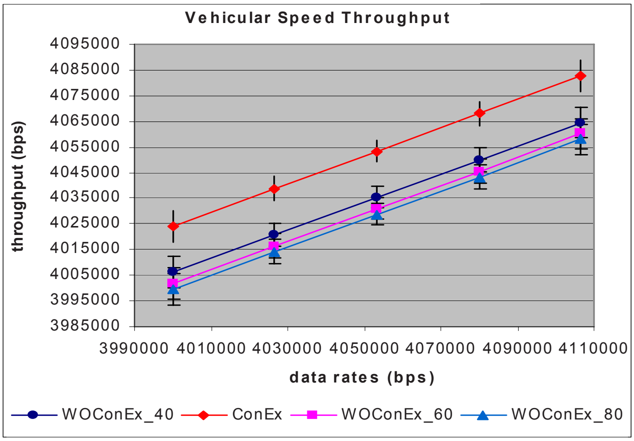

Fig 8. Walking Speed Throughput Analysis

Moreover, there is a significant increase in the packet loss as the speed increases. This is due to faster cell edge crossing of the default gateway. As the speed increases this happens quicker and in “WOConEx” approach should either increase the agent advertisement frequency through agent solicitations or thought more frequent binding updates to overcome the problem of increased packet loss, with the additional cost of the additional overhead. In “ConEx” approach, this is avoided by detecting network detachment before the cell edge is passed.

5 Conclusions

We have discussed CA3RM-Com, the generic context aware architecture proposed for adaptive real time communications in mobile networks. The architecture is flexible and can support adaptations ranging form application adaptations to channel adaptations. Context exchange across the protocol stack enables the adaptation to dynamic situations in mobile networks. Context is represented using context space which is a generic representation of situations which consists of context parameters at each layer and performance parameters. Local packet analyzer is utilized in context acquisition to minimize changes to the existing protocols during the process of acquiring the context. This ensures the modularity and capability of non-cross layering protocols to function in the existing stack. Event driven context exchange through subscriptions and notifications are facilitated by context exchange module. Moreover, CA3RM-com supports local and global context awareness through it ConEx module. Context Manager enables policy based system driven adaptations and controls adaptations avoid conflicts which would consequence performance degradations.

Simulation was carried out for context aware adaptive multi-homed mobile IP which enables adaptive handover based various context and performance parameters. Simulation results showed that the mobile IP handover latency can be minimized with adaptive handover decisions and hence the quality of real time traffic can be improved. Results of pedestrian and vehicular mobility scenarios were analyzed. Performance oriented prototype development of the CA3RM-Com architecture is in ongoing.

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