Context Modeling for Cross-layer Context Aware Adaptations

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Abstract

Demand for real-time services over the Internet while moving, is growing rapidly. This necessitates efficient delivery of wireless real-time traffic. Limitations of existing layered protocol stack for wireless networks lead to the proposal of cross-layer interactions as an alternative solution. At the same time, next generation ubiquitous computing drives wireless applications and protocols to be context aware. A generic context aware architecture with context modeling can aid increasingly demanding real-time applications over highly dynamic wireless networks to be cross-layer context aware and adaptive. Moreover, a generic architecture can make lower layer protocols to be context aware and adaptive to various situations dynamically. This article discusses the adaptive approach supported by proposed cross layer context aware architecture called CA3RM-Com. The scope of this article is to discuss context modeling specifically and address the issue of context representation of multi-layer context for various adaptive situations. Various single layer and multi-layer cross-layer adaptations and the representation of context parameters with respect to each layer of the protocol stack is discussed. We discuss how these adaptations can be operated in the proposed CA3RM-Com architecture. Context aware adaptive multi-homed Mobile IP is discussed as an example adaptation that the architecture can support. Moreover, the extended simulation of context aware adaptive multi-homed Mobile IP is discussed.

Index Terms—Context Awareness; Real-time Communications; Mobile IP

1. Introduction

Rapid growth of Internet, increasing demand to stay connected while on the move are the driving forces of evolving wireless technologies. Demand for real time wireless traffic such as voice, multimedia teleconferencing, mobile PC, mobile TV, mobile games and video conferencing is increasing day by day. Moreover, next generation computing is becoming ubiquitous necessitating wireless technologies to accomplish context aware adaptations [1].

Unlike in static wired networks, wireless networks require adaptations to various situations for efficient real-time communication. The reasons for such adaptations are the challenges arise due to nature of wireless networks, wireless devices in use and characteristics of real-time media. Wireless networks have inherent limitations of radio links such as noise, shadowing, channel fading and interference; network topology is unpredictable due to highly dynamic nature; network management and routing is complex compared to static wired networks. Moreover, there are constraints in wireless network devices in terms of energy and computational capabilities. On the other hand, real-time applications are bandwidth intensive, latency sensitive and loss tolerable in nature [2]. Real-time applications demand for high data rates and are coupled with stringent delay constraints. These data packets should be delivered with tolerable delays and loss rates to avoid decode errors and to guaranty the Quality of Service (QoS) levels. Even though the technology is growing and trying to satisfy the growing demands of applications, there exists an impediment in wireless networks due to the dynamic nature and limited resources of the underlying network compared to wired networks [1]. Because of this, the next generation wireless technologies should facilitate adaptations to various situations dynamically. Challenge in facilitating dynamic adaptations is the awareness of the situations.

Modern communication systems use layered protocol stack for inter-networking due to several reasons. The initial purpose of layering [3] was to ensure modularity. In a modular system, each module has clearly defined functions, procedures, specified and controlled interactions among modular component to enable layer independence. Because of the abstractions, the overall system is easy to understand.

Hence, layered approach reduces system design complexity. So, layering ensures easy implementation and maintainability. Moreover, the layered approach assures the interoperability between different systems. Standardized abstractions allow designers of various subsystems to focus on their particular subsystem without bothering about the entire system interoperability.

Though strict layered approach serves as an elegant solution for inter-networking static wired networks, it is argued in the literature that the layered protocol stack is not adequate for efficient functionality of wireless networks [4],[5]. The layered protocol stack is insufficient to cater for the adaptations of demanding applications and complex networking conditions. Further, the system performance improvements are restricted in layered approach, because most of the time performance improvement is achieved through multi-layer joint interactions.

The rest of the article is organized as follows. Section 2 discusses the background and related work. Section 3 presents motivation of the context modeling, classification of context parameters related to adaptive situations and context representation mechanism we propose. Section 4 discusses the simulation of context aware adaptive handover. Finally, Section 5 concludes the article.

2. Background and Related Work

2.1 Cross Layer Design

Cross-layer interaction was proposed as a solution to overcome limitations of layered protocol stack when applied in wireless networks [6]. Cross-layer design is defined as ***Protocol design by the violation of a reference layered communication architecture with respect to that layered architecture*** *[7].*

According to aforementioned definition, designing protocol by violating the reference architecture, by allowing direct communication between protocols at nonadjacent layers or sharing variables between layers is cross-layer design with respect to the reference architecture. It is argued that violation of layered architecture includes creating new interfaces between layers, redefining the layer boundaries, designing protocol at a layer based on the details of how another layer is designed, joint tuning of parameters across layers and giving up the luxury of designing protocols at different layered independently [7].

A number of cross layer designs are proposed in the literature including [8], [9], [10], [11], [12]. They can be classified as specific solutions and generic architectures.

Specific solutions are not based on the objective of providing a generic framework and are tailored towards a specific adaptation/requirement. Joint adaptations with multi-layer interactions were proposed with various performance objectives. Joint adaptations of adaptive routing and rate/channel adaptations are proposed in [13]. Joint congestion Control, rate control, adaptive routing and channel scheduling is proposed in [14]. Cross-layer mechanism of joint channel scheduling and rate/channel adaptation is presented [15]. Congestion control together with channel scheduling is proposed in [16]. Adaptive routing with joint link rate adaptation is discussed in [17]. Link rate adaptation ([12], [18]) and joint power control is studied in [19]. Joint application layer and lower layer interactions are also presented. Packetization with joint link rate adaptation ([11],[20]), Packetization with joint adaptive routing [21], Packetization with adaptive routing and adaptive modulation are studied in [22]. Energy optimizes routing was proposed in [23]. QoS Control with joint adaptive modulation and power Control at physical layer is studies in [2]. Study related to QoS control with joint channel scheduling is presented [24]. Moreover joint rate control, adaptive routing, channel scheduling and link rate adaptation are studied in [25] and [26].

The frameworks which are based on generic cross layer design are considered in detail for further analysis as bellow.

Cross-Layer Signaling Shortcuts-CLASS. The cross-layer signaling design framework suggests in [4] is called Cross-Layer Signaling Shortcuts (CLASS). CLASS proposes direct signaling between non-neighboring layers. Internal message format of CLASS is defined with the objective of supporting local adaptations. External information flow is based on standard ICMP and TCP/IP headers.

The direct signaling across the layers proposed by CLASS inherently has a very low latency. The mechanism is highly flexible, because any protocol or application at any layer can exchange context. So, wide range of adaptations can be supported. Internal signals are light weighted but the external messages are wrapped in either ICMP or TCP/IP headers so, it introduces some overhead. Hence, average signaling overhead of internal and external context exchange is moderate. However, direct interaction among the protocols introduce high design complexity and hence, maintenance difficulty. Moreover, CLASS proposal violates the concept of layered protocol stack by direct signaling among layers for performance objectives.

Cross-layer Coordination Planes. A framework based on cross-layer coordination planes for wireless terminals is proposed [27]. Cross-layer coordination model composed of four coordination planes where each of them is a cross-section of layered-protocol stack. The planes are classified according to the functionality as security, QoS, mobility, and wireless link. Internal details of signaling and interactions are not available.

Coordination planes separate the wireless networking problems from the existing functionality of the layered stack hence ensures uninterrupted operation to existing stack. So this concept has high degree of coexistence in the existing layered stack. Due to the cross-section views introduced as coordination planes the modularity of the proposal is low. Implementation and changes to the existing protocols and proving operations of planes is complex. Similarly maintenance is also difficult due to the complexity in changing and evolving the protocols. Flexibility is low since the adaptations are limited to the once defined in coordination planes. Moreover, the system cannot support adaptations which may involve interaction among the planes and scalability is low.

WIreless DEployable Network System-WIDENS. The WIreless DEployable Network System (WIDENS) [28, 29], is a ad-hoc communication system specifically designed for public safety or emergency applications. WIDENS architecture supports combination of several joint optimizations such as secured QoS extension for route optimization, mobility management, resource allocation at the MAC layer with hard QoS support, combine opportunistic scheduling and channel coding, slotted multiuser/stream capability.

WIDENS cross-layer architecture preserves modularity to a great extent, by allowing layer by layer interaction. The cross-layer interaction is separated from non-cross layer information flow, so the solution can coexist with the existing layered protocol stack. However, providing mapping function with the separated standard protocol functionality is complex and demands synchronization mechanisms. Further, to support wide range of adaptations it demands complex and considerable amount of changes to the protocol stack. So, design complexity is high introducing difficult maintainability. The processing overhead of context passes to the next layer is very high due to mapping of state information and parameters of adjacent layers. In addition to that, latency of layer-by-layer traversal and processing at each layer is very high. However, unnecessary and unintended cross-layer operations are avoided by controlling information flow through the translation at each layer. Flexibility of the architecture to support range of adaptation is low. Each newly added adaptation requisite changes to whole protocol stack that the packets flow through.

ECLAIR Cross-layer Architecture. ECLAIR architecture proposed [8], is based on the fact that protocol behavior is determined by the protocol data-structure. ECLAIR provides an interface to read and update the protocol data-structures through the interface called a Tuning Layer (TL) for each layer. TL is further divided in to generic tuning layer nad implementation specific tuning layer for portability objectives of implementation. Cross layer feedback algorithms and data structures are added in to Protocol Optimizers (PO). The collection of POs forms the Optimizing SubSystem (OSS).

ECLAIR cross-layer architecture is separated and can be easily enabled/ disabled it facilitates the uninterrupted operation to the layered protocol stack. Modularity of the system is high because it allows layer separation and preserves the modular functionality. Cross-layer interaction can be facilitated at any layer, and the solution can be extended to range of adaptations and optimizations through OSS. So, the scalability of the architecture is high. However, the design involves changes to almost every protocol that uses context as well as providing the context. So, maintenance and management of product is difficult and it hindered the evolution. In addition to that, there exists an extra complexity in implementing TLs and POs. Further, TLs and POs add extra signaling overhead and latency.

Cross-Layer Decision Support Based on Global Knowledge-CrossTalk. A cross layer architecture called CrossTalk for decision support based on global knowledge is proposed [9]. CrossTalk enables mobile devices to establish the state of the mobile node as a *local view* and relative status called *global view* compared to global network conditions. Local view is represented as the sum of local parameters such as battery level, SNR, location information, transmit power, etc. Global view is based on the metrics such as energy level, communication load or neighbor degree. The CrossTalk architecture consists of two data management entities to manage aforementioned two views. CrossTalk proposes local adaptations of the mobile device based on the global status. Global view is encouraged to use whenever possible to have network wide accurate decisions.

CrossTalk proposes a comprehensive network wide decision mechanism. The architecture can coexist with the layered architecture with uninterrupted operation to the stack. However, CrossTalk does not address the local view in detail for example how the local parameters are acquired by the local view management entity and how they are exchanged to the interested protocols. Further, establishing a global view and data dissemination is costly and complex. Solution is less flexible in local adaptations and performance improvements because of the lack of support for local adaptations. Latency and overhead is high due to complex network wide data dissemination procedure. Local data accessibility and dissemination procedure is not addressed and information about modularity of signaling mechanism is not available.

Local Server based Cross-Layer Coordination Framework. A cross-layer coordination framework which consists of a local cross-layer coordination server and clients at each layer is suggested in [30]. Non-adjacent layer interaction is done through the cross-layer server. Context delivery is performed in a way that, when an initiating layer wants to send a certain event to another target layer, the client of the initiating layer first sends event to the server, and then the server forwards it to the target layer. How the interested cross-layer protocols and applications can express interest for context is not addressed. A parameter repository is maintained at the server.

The framework preserves the modularity while maintaining a higher degree of flexibility by allowing interaction among non-adjacent layers. Since the cross-layer interactions are separated from the standard operational protocol stack, coexistence of the framework with the layered stack is high. However, since the layers that support the parameters also need to be changed and all the adaptations are maintained at the layer client itself, the design complexity of the framework is high. Since the parameters traverse through server and client are kept in a repository rather than notifying the interested layers as an when the event occurs, there is a latency of the signaling. Signaling overhead is low because the event structure composed of few fields.

2.2 Context Aware Adaptations

A general definition of context for context aware computing domain is presented in [31]. According to the definition provided in [31] context is: ***any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.***

Challenges in context aware computing, include uncertainty, diversity and complexity of context information. Research had been tried to investigate important aspects of context aware computing such as context discovery, context presentation, and context execution including reasoning to address aforementioned challenges [32, 33, 34, 35].

Context Modeling. Context representation and modeling has been addressed various domain specific requirements to describe context. Mark-up based models extend existing web standards such as XML [1] and RDF [2] to represent contextual information. Composite Capability/Preference Profiles (CC/PP) [3] is a data representation mark-up format based on RDF, which is proposed to describe user agent and proxy capabilities and preferences. The Comprehensive Structured Context Profiles (CSCP) context model which overcomes structural shortcoming of CC/PP is proposed in [36]. XML based context representation is proposed in [37]. XML is used to encode context configurations and values, and XML associated tree structure and XML schema are used to represent richer data and meta-data. A context modeling approach called Context Spaces which describe context and situations with spatial metaphors of state and space is presented in [38]. Context Space explicitly models context and situations in general rather representing specific contextual information.

[1] urlhttp://www.w3.org/XML/
[2] urlhttp://www.w3.org/TR/1999/REC-rdf-syntax-19990222/
[3] urlhttp://www.w3.org/TR/2001/WD-CCPP-struct-vocab-20010315/

3 Context Representation and Support for Adaptations

3.1 Motivation

A number of research studies has been done in specific cross-layer adaptations as discussed in Section 2. Almost none of studies address the context awareness in cross-layer signaling in great detail. None of the studies present a clear, generic way to model context parameters. None analyses the context at various layers of the protocol stack relation to each adaptation.

The generic architectures address the context exchange and signaling mechanisms and very few studies try to address context acquisition including [4, 39]. To facilitate context awareness it is necessary to investigate other aspects of context awareness mentioned in 2.2 in addition to the signaling mechanisms (context exchange) addressed in the cross-layer architectures. Generic mechanisms for context presentation and context acquisition are key aspects which are missing in the generic cross-layer architectures proposed in literature. In addition to that, clear definition of context parameters used in specific adaptations and applications is necessary in order to facilitate control over multiple adaptations to avoid performance degradation of wholes system.

3.2 Classification of context parameters

A detail classification of context parameters used in various cross-layer context aware adaptations discussed in Section 2 is presented in this section. Table 1 shows the identified layer parameters related to adaptations at each layer. This parameter identification is based on the review of the specific adaptations found in the related work.

3.3 Context Aware Architecture

We propose the CA3RM-Com architecture [44] as a generic cross-layer context aware framework. The architectural details, design principles are discussed in [44]. The CA3RM-Com architecture and its modular components are illustrated in Figure 1. The CA3RM-Com architecture composed of several components to facilitate aspects of context awareness. The components are Context Exchange Module (CEM), Context Acquisition Module (CAM), Context Representation Module (CRM) and a Context Management Module (CMM). Context exchange across the protocol stack and across the network is carried out through the CEM which is called ConEx [45]. ConEx is an event driven

Table 1. Context Parameters of Layer Adaptations

Adaptation	Layer	Parameter
Application Layer Adaptations		
QoS Control ([25], [2], [26], [24])	Application Layer	user application priorities, user QoS preferences (delay sensitivity, loss tolerance), Source distortion, packet loss rate, video source coding, user satisfaction (MOS), PSNR
	Link Layer	packet Size
	Physical Layer	modulation, code rate, symbol rate
Packetization ([21], [11], [20], [40])	Application Layer	QoS (delay sensitivity)
	Data Link Layer	channel rate, multiple access, network access delay, error detection (retry limits, frame length, BER)
	Transport Layer	hybrid ARQ error control
	Physical Layer	modulation, antenna diversity, power delay profile, time delay profile, time delay speed, transmitter signal power, maximum adaptation frequency, battery power
Transport Layer Adaptations		
Mobility Adaptations ([41])	Network Layer	hand over notifications
Congestion Control/Rate Control/ Error corrections ([14], [10], [16], [25], [26], [40])	Application Layer	service quality, source bit rate
	Transport Layer	Congestion distortion, receiver window, timeout clock, congestion window, TCP/UDP header checksum, TCP/UDP header options, serial number of corrupted packet
	Network Layer	route data(route failures, route changes)
	Data Link Layer	SNR, BER, error coding, channel conditions (channel access delay, congestion)
Network Layer Adaptations		
Adaptive routing ([14], [13], [10], [25], [26], [22], [21], [23], [17], [19], [12], [18])	Application Layer	traffic type, delay bound, transmission delay jitter bound
	Network Layer	routing metrics, route outage probability, number of nodes in routes, network packet size(routing protocol), bit rate
	Data Link Layer	link outage probability, network congestion, packet delay, link state routing, average SNR, SNR threshold
	Physical Layer	battery power, min transmission power, path loss exponent, transmission range
Mobility Management ([42], [43])	Application Layer	Application/User QoS requirements
	Data Link Layer	Link layer hand over triggers
Data Link Layer Adaptations		
Scheduling and Adaptive Error Control ([14], [10], [15], [16], [25], [26], [24], [40])	Application Layer	service quality
	Network Layer	routing data (route failures, changes)
	Data Link Layer	SNR, link transmission rate, packet size/length, symbol rate, constellation size, error control system, channel conditions (packet loss, sequence number of packets), network delay, congestion(queue length, average link layer utilization), link BW, PER,RTT, Time slots, queue of packets per user, partial checksum
	Physical Layer	channel conditions (equalizer information -fading.), battery power
Channel/Rate adaptation ([25], [20], [23], [17], [12], [18])	Application Layer	transmission rate
	Data Link Layer	SNR, BER, error detection (retry limits, frame control), BW, link capacity, outage probability of links, link transmission rates
	Physical Layer	interference, SNR, noise, fading
Physical Layer Adaptations		
Adaptive Modulation/Transmission mode ([25], [26], [22], [2])	Application Layer	service quality
	Network Layer	Routing data/traffic, network data rate
	Data Link Layer	SNR, payload data,
	physical Layer	mode, Channel fading, channel code rate, modulation, bytes per symbol, BS-user gain, transmit power, SINR
Congestion Recognition	Physical Layer	load estimation intra-cell interference, Base station transmit power
Power Control ([10], [2], [11], [23], [19])	Data Link Layer	angle of arrival (AOA) of RTS, CTS, transmission rate
	Physical Layer	energy usage (CPU, network)

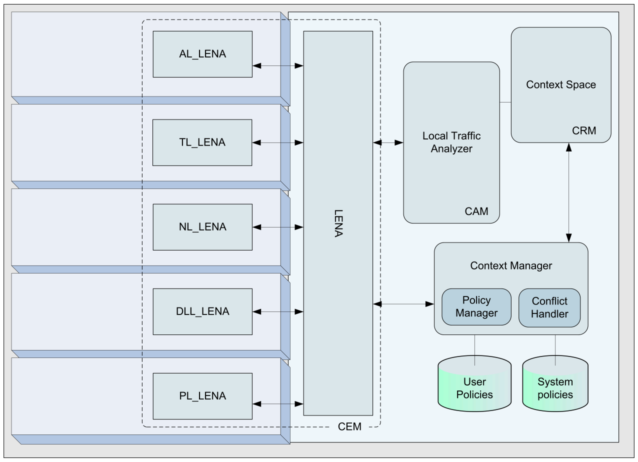

Figure 1. Cross-layer Context Aware Architecture

context exchange framework in which context delivery is based on subscriptions. Details about ConEx, the algorithms and message formats are presented in [45]. Modeling of ConEx is presented in [46]. Light weighted message format of ConEx ensures low overhead of context exchange mechanism. Event driven context exchange through subscriptions and notifications facilitated by ConEx ensures low latency in context delivery. ConEx preserves modularity of the protocol stack by enabling cross-layer signaling through layer agents and by restricting the direct interaction across protocols at non adjacent layers. Context acquisition is accomplished through the Local Traffic Analyzer CAM, which sniffs the packets flow through the protocol stack. Local packet analyzer is utilized in context acquisition to minimize changes to the existing protocols during the process of acquiring the context and to introduce the uninterrupted functioning of non-cross layering protocols in the existing stack. CAM exchanges context via ConEx. Context is represented using context space which is a generic representation of situations which consists of context parameters at each layer and performance parameters. Moreover, CA3RM-com supports local and global context awareness through it ConEx module. Context Manager enables policy based system driven adaptations and controls adaptations to avoid conflicts which would consequence performance degradations. The architecture is flexible and can support adaptations ranging from application adaptations to channel adaptations. Architecture can be easily enabled and disabled hence ensures higher degree of coexistence with the existing layered protocol stack.

3.4 Context Representation Module

Context representation is a key aspect in any context aware system. CA3RM-com architecture exploits extended multi-layer version of Context Space [38] to represent context parameters and performance optimizing metrics used in cross-layer adaptations.

Figure 2 illustrates the representation of context parameters and performance parameters in Euclidean vector space for a given problem domain. These set of parameters represent a situation. Combination of context and performance parameters (could be static or dynamic) form the context vector of a particular situation.

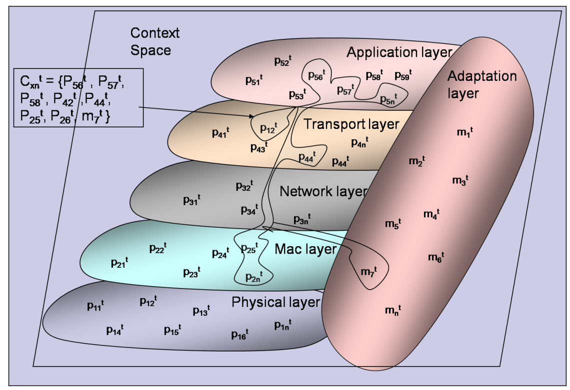

Figure 2. Multi-layer Context Representation

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.

$$V_t = \sum_{i=1}^{n} a_i cp_{xit} + \sum_{j=1}^{m} b_i pp_{it} \tag{1}$$

Where, a_i , b_i are scalars.

x indicates the layer number 1 to 5, which represent the physical, mac, network, transport, and application layers of the practical protocol stack.

cp_{xnt} is the n^{th} adaptation parameter at layer x at time t.

pp_{nt} is the n^{th} performance parameter at time t.

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

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

Further, granularity is introduced to dynamic parameter ranges in order to provide reasoning and more reliable decision making about the situation as shown in Table 2. For example, parameter cp_{11t} context space values range from $r1_l cp_{11t}$ to $rn_u cp_{11t}$. where, $r1_l$ represents lower bound and

rn_u represents the upper bound. The context value range is subdivided in to n number of ranges.

Table 2. Context parameter value ranges

Range	Parameter values
$range_1$	$r1_l cp_{11t}$ - $r1_u cp_{11t}$
$range_2$	$r2_l cp_{11t}$ - $r2_u cp_{11t}$
.	.
.	.
.	.
$range_n$	$rn_l cp_{11t}$ - $rn_u cp_{11t}$

3.5 Context Management Module

Context Management Module (CMM) in CA3RM-Com architecture 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. Two main categories of adaptation are considered in the proposed CA3RM-com architecture as illustrated in Figure 3.

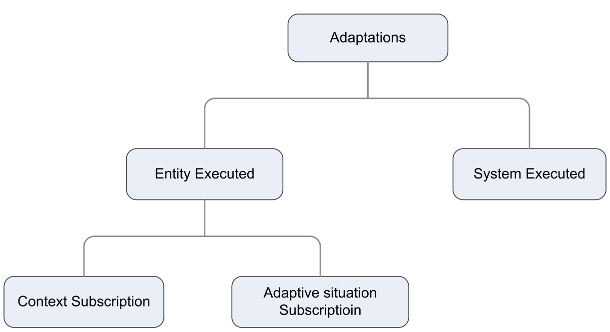

Figure 3. Categorization of Adaptations

The two categories of adaptations, *entity-executed* adaptations and *system-executed* are supported in the architecture. In *entity-executed* adaptations the *entity* (the term entity is used to represent any protocol or application at any layer of the protocol stack) which is executing the adaptation subscribes to the architecture to acquire the context.

Entity-executed adaptation can be achieved based on two types of subscriptions. In one type of entity-executed adaptations the entity requests particular context parameters in order to make the adaptation decision based on its own rules or policies and conditions. In the other type of entity-executed adaptations, entitys subscription is to an adaptive situation, where the policy manager executes the policies related to the adaptation and notifies the adaptation decision to the relevant entity [1]. 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 enables control and administration of the system [1].

4 Simulation

4.1 Adaptive Handover

We have evaluated the context aware adaptive Multi-homed Mobile IP [47] handover mechanism based on the proposed CA3RM-Com architecture in simulation. The detail discussion of algorithm and simulation of handover scenario is out of scope of this article. In this section we discuss the simulation in brief and the extended experiments with multiple candidate networks to provide a validated example of adaptation that CA3RM-Com can support. In brief, context aware adaptive Multi-homed Mobile IP handover is an adaptive mechanism is an entity-executed adaptation (as discussed above), where the adaptation decision is done by the MIP protocol itself based on the subscribed context parameters. We show overall handover delay can be minimized by fast agent discovery and fast move detection and context aware decision for adaptation to mobility can be made. Hence increased throughput and minimized packet loss is achieved through fast handover. In context aware adaptive handover, fast movement detection was done using SNR based movement prediction without waiting for the conventional unreachability detection. The least congested GW is selected based on RNL metric [48].

The extended simulation presented here is based on the topology shown in Figure 4 with multiple candidate networks, where more than one possible approaching gateways are available for the MN for handover. Results are presented as mean value of multiple simulations with different seeds to use normal distribution. Results are presented with 90% confidence level.

Context space discussed in section previously is used as shown in Figure 5. The context vector for adaptive handover is shown in Equation 3 and the range of values of the parameters in Table 3. Granularity of SNR and RNL is shown in Table 4.

$$\begin{aligned} V_{ah} := a_1.snr + a_2.snr_{th} + a_3.snr_{cth} + a_4.ctp \\ +a.5.cps + a_6.cbf + a_7.cdr + a_8.rnl \\ +a_9.aaf + b_1.pl + b_2.thr \end{aligned} \quad (3)$$

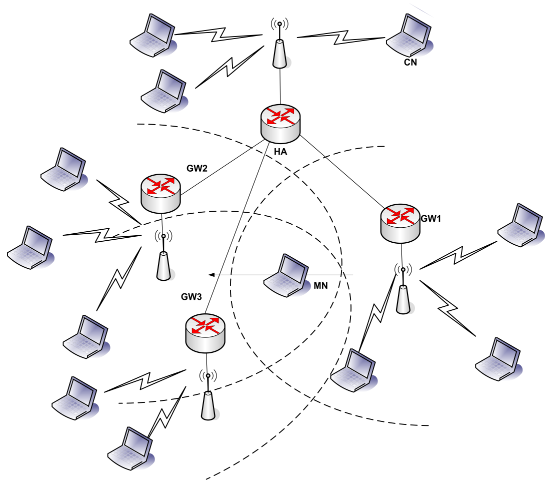

Figure 4. Simulation Network Topology

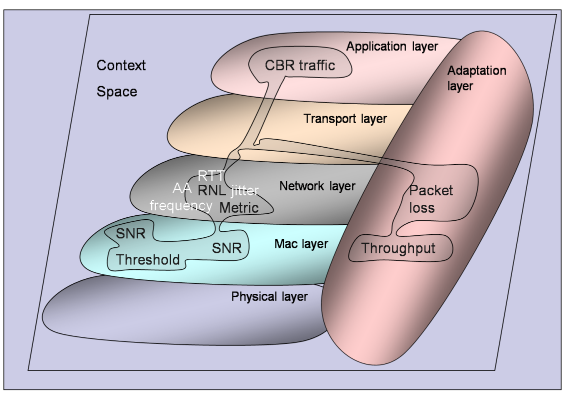

Figure 5. Context Space for context aware handover

Table 3. Context Parameters of Adaptive Handover simulation

Symbol	Parameter	Range of Values/Value
V_{ah} : Adaptive Handover		
snr	SNR of agent advertisements	>10dB
snr_{th}	radio receiver SNR threshold	10dB
snr_{cth}	CBR traffic SNR threshold	15dB
ctp	CBR traffic priority	0/1
cps	CBR packet size	(1460) Bytes
cbf	CBR packet interval	(0.003-0.011) second
cdr	CBR data rate	(4-4.2)Mbps
rnl	RNL metric	0-1
aaf	agent advertisements frequency	2 per second
pl	CBR pakcet loss rate	(0 - 1)% [4]
thr	CBR throughput	(3.96 - 4.22) bits per second

Table 4. Parameter ranges of SNR and RNL

SNR	
SNR Range (dB)	**Relationship to channel quality**
<15	very poor
15 to 20	poor
20 to 30	good
>30	excellent
RNL	
RNL	**Relationship to congestion**
0.1 to 1	poor
.01 to 0.1	good
0 to 0.01	excellent

SNR is Signal to Noise Ratio of received agent advertisement in multi-homed MIPV4 or binding updates of Multi-homed MIPV6. Context parameters such as RTT, jitter and frequency of agent advertisement are used to calculate RNL metric. Simulation of the proposed solution was carried out using the network simulator Glomosim. Time out for bindings used is three times the agent advertisement time. Simulation was carried out for 200 seconds. Constant Bit Rate (CBR) traffic flows were sent from MN to CN every 3MS. Results of different data rates with different packet sizes were simulated. Agent advertisements in the MIP were sent every half a second and MN registered every third advertisement with the HA.

Pure M-MIP approach, which does not use context exchange for handover decision is represented as *WithOut ConEx* (WOConEx) approach. Adaptive handover decision and is based on ConEx architecture is referred to as the *ConEx* (ConEx) approach.

Figure 6 illustrates the packet loss rate of CBR traffic with variable data rates. Due to the delay of move detection in *WOConEx* approach a considerable packet loss is noticed. In *ConEx* approach the move detection delay is zero with the proactive move detection technique. So the packet loss rate is zero in *ConEx* approach. The graph in Figure 7 illustrates the throughput results of CBR traffic for variable data rates. In the *WOConEx* approach, there exists a delay for move detection, which causes the packet loss. Due to this packet loss during the handover in this approach, the throughput is decreased. In *ConEx* approach the move detection is done proactive without a delay. Hence to-

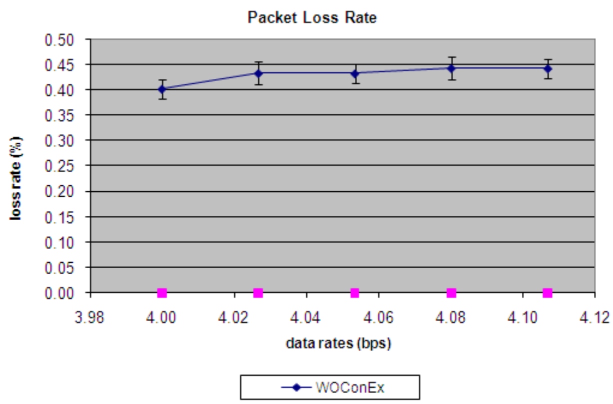

Figure 6. Packet loss rates of CBR traffic

tal handover delay is reduced and maximum throughput is available in *ConEx* approach compared to *WOConEx* approach.

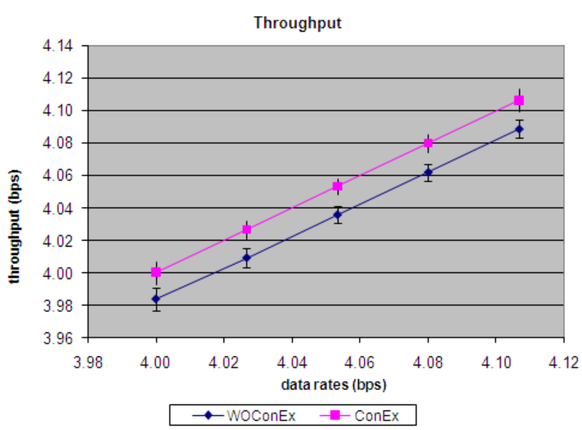

Figure 7. Throughput results of CBR traffic

4.2 Context Representation Extensibility

The proposed CA3RM-Com architecture is extensible to support various single layer and multi layer context aware adaptations. These adaptation techniques can be entity-executed or system-executed based on the application and the policy managers system policies.

User Perceived Quality Maximization. CA3RM-Com architecture can be used in user perceived quality maximization discussed in [24]. The context vector corresponds to the adaptive quality maximization of video applications is shown in Equation 4. Static parameter values and ranges of parameter values for dynamic parameters of context space are shown in Table 5. MOS values between 0 to 4.4 are used to represent user satisfaction.

$$V2: upqm = a1.m + a2.cr + a3.smr + a4.snr + b1.mos + b2.us + b2.abs + b1.psnr + b2.sl + b3.us \quad (4)$$

Table 5. User Perceived Quality Maximization

Symbol	Parameter	Range of Values/Value
V2upqm - User Perceived Quality Maximization of video		
m	Modulation scheme	DBPSK, BPSK, QPSK, 16-QAM, 64-QAM, DQPSK
cr	Channel Code rates	1/2,4/3,2/3
smr	Symbol/modulation rate	(500, 700,900)kSymbolds/s
snr	Signal to Noise Ration (SNR)	(7-25) dB
mos	Mean Opinion Score (MOS)	0-4.4
psnr	percieved SNR (PSNR)	(50-200)kbits/s
sl	slice losses	0-15%
us	user satisfaction	very satisfied, satisfied, some users dissatisfied, Many users dissatisfied, Nearly All users dissatisfied, Not recommended.

TCP congestion & flow control. TCP congestion and flow control mechanism is proposed in [49]. The context vector representation of this adaptation in CA3RM-Com architecture we propose is shown in Equation 5. Static parameter values and ranges of parameter values for dynamic parameters of context space are shown in Table 6.

$$V3: tcp = a1.up + a2.bw + a3.rtt + a4.aw + b1.thr \quad (5)$$

Energy Optimized Routing. Context modeling proposed in this article can be extended in energy optimized routing as an adaptation [23, 19]. The context vector representation of this adaptation is shown in Equation 6. Static parameter values and ranges of parameter values for dynamic parameters of context space are shown in Table 7.

$$V4: eor = a1.ps + a2.nn + a3.br + a4.es + a5.tr + a6.ple + a7.mtp + b1.thr \quad (6)$$

Optimal Transmission Mode. Link adaptation/optimal transmission mode for IEEE802.11a is proposed in [15].

Table 6. TCP congestion and flow control

Symbol	Parameter	Range of Values/Value
V3:tcp - TCP congestion and flow control		
up	User priorities	1,2,3
bw	Network BW	100Mbps
rtt	Round Trip Time	about 5ms
aw	Advertised window	8 KB(for transmission $<$ 1 Mbps), 17 KB(for transmission 1-100 Mbps), 64 KB (for transmission $>$ 100 Mbps)
thr	throughput	(500-1060) kbps

Table 7. Energy Optimized routing

Symbol	Parameter	Range of Values/Value
V4:eor - Energy Optimized routing		
ps	Network packet size	512B
nn	number of nodes	10-25/25
br	bit rate	2Mbps
es	Energy Saving	(0-100)%
tr	Transmission range	150-250m
mtp	Min transmit power	280mW
ple	Path loss exponent	4
thr	throughput	(0-200)kbps

The context vector representation of adaptive transmission mode is shown in Equation 7. Static parameter values and ranges of parameter values for dynamic parameters of context space are shown in Table 8.

Table 8. Optimal transmission mode

Symbol	Parameter	Range of Values/Value
V5:otm - Optimal transmission mode		
tm	Transmission mode	1, 2, 3 ,4 ,5, 6, 7, 8
snr	SNR region (dB)	0-5(Not used) , 5-9, 9-11, 11-15 , 15-20, 20-21, 21-30
cr	Code rate (FEC)	1/2, 3/4, 1/2, 3/4, 1/2, 3/4, 2/3, 3/4
bps	bytes per OFDM symbol	3, 4.5,6,9,12,18,24,27
dr	Network Data rate (Mbps)	6, 9, 12, 18, 24, 36, 48, 54
m	modulation	BPSK, BPSK, QPSK, QPSK, 16-QAM, 16-QAM, 64-QAM, 64-QAM
pl	payload data	16000 bits
thr	throughput	(0-200)kbps

$$\begin{aligned} V5: otm = a1.tm + a2.snr + a3.cr + a4.bps \\ +a5.dr + a6.pl + a7.m \\ +b1.thr \end{aligned} \tag{7}$$

5 Conclusion

Cross-layer adaptations proposed in the literature are classified based on the layer in which the adaptation is executed. The context parameter set for the adaptations, relevant to each layer is identified. We have presented context modeling mechanism for cross-layer context aware adaptations in proposed CA3RM-Com architecture. CA3RM-Com is the generic architecture proposed to support adaptation through the multilayer context exchange based on interest, maintaining the system modularity. Various adaptations and relevant context representation that CA3RM-Com can support are discussed. Context-aware adaptive handover is used to illustrate the context modeling. The extended simulation of context aware adaptive Multi-homed Mobile IP handover and the performance improvements of the simulation results are discussed. Identification of dependency relationships and conflicts among adaptation parameters with the objective of system stability is a open research area to be addressed in future work.

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