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Cross Layer Design Approach for Future MANET Applications

Sadanand R. Inamdar[1], Sathish Babu B.[2], Ravi M. Yadahalli[3]

[1]Research Scholar, Dept. of CSE, SIT, Tumkur, Karnataka, India
[2]Prof. Dept. of CSE, SIT, Tumkur, Karnataka, India
[3]Prof. Dept. of ECE, SGBIT, Belgaum, Karnataka, India
[1] inamdars09@gmail.com; [2] bsbit@gmail.com; [3] yadahalliravim@gmail.com

Abstract— Cross-layer architecture, a new design paradigm that enables information sharing across the layers promises to achieve optimization of conflicting objectives that otherwise considered as independent of each other in the context of emerging applications of ad hoc networks. Quest for a high throughput, low latency and tangibly better scalability requirements of ad hoc network applications in present 3G/4G and future 5G standards become critical challenge without the aid of inter layer interaction. This paper discusses the perspective scope of cross-layer technologies in the context of ad hoc networks to meet the aspiration set forth under high user/traffic intensity applications.

Keywords— Cross layer design, MANET, optimization, mobility, medium access control protocol.

I. INTRODUCTION

An ad hoc network refers to category of wireless networks that are portable with connected devices which have an identical status on a network and undisputed movement facility. The nodes are free to associate with other available nodes provided they are under its communication range, must act as router/relay and have the responsibility to control plus organize the network effectively. The advantages of ad hoc networks like mobility, flexibility, resilience and independence of fixed infrastructure spark off many vision based applications in several fields. Some of them are mission critical emergency crisis management services to instantaneously set up the network with lower cost, business environment that require collaborative computing outside the office environment and game theory that deals with multi-person decision making, in which each decision maker tries to maximize his utility. The Personal Digital Assistant (PDA)s, such as wearable computers and smart phones having Wi-Fi and IEEE 802.15 technologies are being used to develop applications like off-campus

users to attend conferences, to remotely control lighting/temperature at home and for vehicles to cooperate in sharing state of the road etc.[1].

Based on their purpose of usage the wireless ad hoc networks are distinguished in three categories; Mobile Ad hoc NETwork (MANET) that consist of devices like smart phones and laptop computers, Vehicular Ad hoc NETwork (VANET) composed of travelling cars to create a mobile network and Wireless Sensor Network (WSN) made up of autonomous sensors to control the environmental actions [2]. The dynamic Quality of Service (QoS) requirements in emerging multimedia service based applications of MANETs are always challenging for the reason that communication link is mostly time varying natured. The Cross Layer Design (CLD) approach based on interaction that allows for fine tuning and dynamic adaptation of parameters of protocol during design phase to optimally allocate critical resources in run time has emerged as one of the solution in several applications of MANETs. Mobility of nodes in MANETs poses challenges like; more frequent path breaks and sub-optimal path. Though dynamic network topology higher the chances for node to break its link with neighbor node, at the same time it higher the possibilities of discovering shorter path to its destination in case mobility follows group mobility pattern [3]. Generally it is possible to setup interlayer interaction across the layers in a timely manner during network operation for sharing information between layers to ensure adaptability and to produce higher network efficiency for given QoS guarantee [4]. This paper provides insight into the potential applications of CLD and discusses the technological challenges that protocol designers and network developers are faced with.

II. CROSS LAYER DESIGN APPROACH

The specific traits of MANET's pose challenges to network protocol design of its layers. The lowest layer called physical layer must concern with instantaneous changes in the link features. The media access control (MAC) layer that handle fair channel access, packet collision conditions has to deal with hidden node and/or exposed node problems. Node cooperation to discover and maintain optimal path is required at network layer. The transport layer need to be capable of handling loss of packets and delay feature that sounds different from wired networks counter parts. Various possible disconnections and reconnections are taken care in application layer. Moreover, developments of all network protocols need to interface smoothly with traditional network architecture to consider possible security issues and QoS needs. Most of protocols proposed for MANETs assume layered architecture design which is highly rigid or strict and each layer specific protocol architecture is only concentrated about the interface to neighboring layers. In recent years, due to availability of several enabling technologies the MANET protocols have given importance on establishing significant interactions among various layers of the network stack to enhance network performance. This CLD approach that, introduces stack wide layer interdependencies is beneficial in dynamic environments of MANETs. The CLD approach makes use of the current state information available throughout the network stack to develop adaptive protocols.

Conceptually the CLD approach to network architecture is place at the connection of the three basic areas as depicted in figure 1 and they are; wireless networking, signal processing and Information theory.

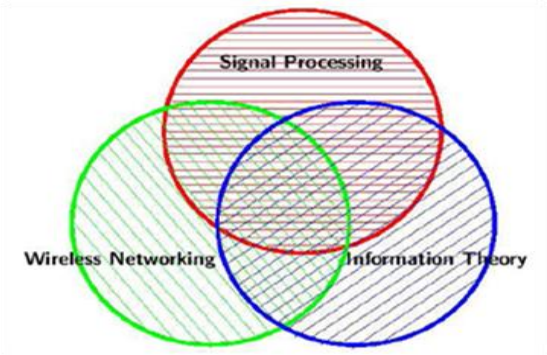

Fig. 1 CLD approach to network architecture

Information theory:

- Design of algorithms for source coding and channel coding
- Developing capacity limits

Wireless networking:

- Traffic theory
- Connection Vs. Connectionless architecture
- Analysis of MANET's energy efficiency
- Design of protocols

Signal processing:

- Reducing (Bit Error Rate) BER
- Transmission energy reduction
- Spectral efficiency (increasing bits/s/Hz)
- Designing and estimation algorithms for multi-access

The purpose of CLD is to connect the resources of all communities together to make a network, which is highly adoptive to changing environment and allow sharing of the information between the individual modules in the system. Several functional requirements such as node mobility management, QoS awareness, node's cooperation, energy conservation and security aspects can be effectively implemented by exploiting and combining mechanisms of all the layers of the MANETs. A way to implement this requires removing the rigid layering in which each layer's protocols are developed in isolation. Approach now needs to use an integrated, intra-dependent and hierarchical framework setup to utilize the advantages of the interdependencies among layers. Type of interactions among layers of the network stack depends on information flow among different layers as illustrated in figure 2.

Application Layer	Energy management Quality of service Security and cooperation Mobility management	Group Communication, Service Locations
Transport Layer		Transport Layer Protocols
Network Layer		TCP/IP routing, Addressing, Forwarding
MAC Layer		Framing, Error Detection and Control, Congestion
Link Layer		Antennas, MAC, Bluetooth, Power Control, 802.11, Hyper LAN.

Fig. 2 MANET functions sharing between different layers through CLD.

The motivations that favour the necessity of CLD in applications of MANETs are:

1. The necessity of network protocols to be adaptive to network dynamics in certain applications.
2. To achieve agility of the protocol wherein adjustment of its behavioural parameters are done according to the present network state.
3. In context aware solutions that uses the metrics influencing the network state like medium status, level of congestion and traffic flow requirements need redesigned protocols that involve interaction between multiple layers.
4. Role of more than one layers is involved to effectively address issues of MANETs like security, energy constraint and topology control. Hence joint solutions framework that involves multiple protocol layers is suggested.

III.CLD METHODS AND EVALUATION

There are four different approaches in the CLD they are: creation of new interface, layer merging, design coupling and vertical calibration [5]. The CLD architecture follows three implementations such as: direct communication between layers, a shared database between layers and a completely new abstraction approach. A set of precautionary measures of CLD should be followed while its implementation [6]. The performance of the CLD architecture depends on following criteria:

- *Dependency*: The CLD architecture contains different types of parameters, which are interrelated. The communication between these parameters is maintained by the dependency graph.
- *Unintended interactions*: The CLD architecture should maintain the record of interactions between layers. Cross layer architectures may ignore the failure of interactions between the nonadjacent layers.
- *Stability*: Evaluation of protocol for stability should take into account the parameters of dependency graph which are usually maintained by two different loops of same protocol.
- *Cost*: To find the cost benefit of the CLD architectures, following cost related parameters need to be considered:
  1. Excessive delays are involved to evaluate objective function with a large range of variables.
  2. It is more difficult to manage and optimize a cross layer architecture that does not provide a good level of modularity.
  3. Communication overhead is involved during the abstraction process that chooses the states information and capabilities of different layers.

A typical example of CLD approach that jointly optimizes transmission rate, transmission powers, scheduling (a function of medium access) and routing has a goal of achieving proportional fairness. In the networks that are developed on physical layers wherein a transmission rate is directly proportional to Signal to Noise Ratio (SNR) at the destination (example include low-gain CDMA systems or UWB), the solution that is optimal uses following mentioned principles:

(1) Lower and upper power limits are ($0 - P_{MAX}$ power control): i.e. node should either transmit with Max power or should remain silent.
(2) Forbidden region is created around the emitter such that all nodes maintain silence during sending, but nodes beyond this region can send simultaneously, without concerning the interference that they create at the destination node.
(3) The level of interference at the receiver is used to vary transmission rate at the sender due to availability of several senders sending simultaneously.

(4) The area of forbidden region is proportional to the transmission power level of the source of the link, and does not depend neither on the measure of the link or positions of neighbors.
(5) Instead of considering longer hops it is recommended to relay on minimum energy and loss of routes.

IV. CLD IMPLEMENTATION

Modularity is attractive feature of Open System Interconnect (OSI) model, these modules have ability to operate under worst condition scenario and communicate in a strict manner using interface called Service Access Port (SAP). The SAP is the means to use well defined function(s) offered by protocol layer via primitive operational methods. The two layers that want to interact may use multiple SAPs based on its intended functions and the information requirement [7]. The resulting software from strict layering can be inefficient in terms of spectrum utilization and energy usage. If layers are designed using cross layer architecture having ability to observe and respond to channel conditions, dramatic improvement in efficiency can be achieved. CLD approaches are considered as inevitable to support many new processes requirements beyond third generation (3G) mobile communication network applications.

Implementation of the cross layer interaction falls into two types: general vs. specific solutions. General solution come with designs that achieve inter layer information flow which are applicable to many network architectures. The specific solutions are dependent on architectures and requirements of particular application and these customized solutions are difficult to adapt for general approach. Optimization of a wireless network system to particular type of MANET application is dependent on parameter like delay tolerance, bandwidth constraint, QoS, its compatibility with existing network architecture and feedback scheme etc. By executing necessary preliminary precautions this new buzz called CLD is utilized by the researcher to develop new types of MANET applications. The system wide close examination of necessity of CLD is essential as longevity of the CLD is yet to be proved in real time [8].

Some of the drawbacks observed in cross layer interaction based design include creation of adaptation loops due to interacting protocols and incorrect system implementation due to dependencies caused by non essential functionalities. Several cross layer interaction found in literature and approach followed in [8] suggest the cross layer solutions as depicted in figure 3 involves layers like Physical (PHY), MAC, Network (NET) and Transportation.

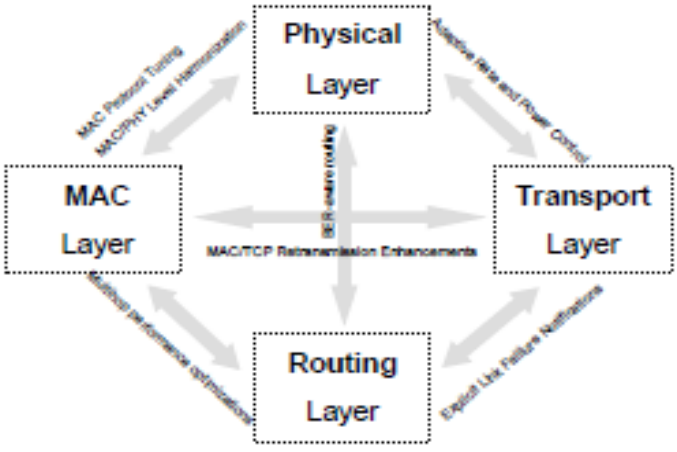

Fig. 3 CLD approach involving bottom four layers of ISO stack

PHY and MAC cross layer interaction based solutions: Functionally, the two neighboring layers namely physical and medium access are closely related due to which most of the protocols suggested for directionally enabled MANETs have tried to optimize their working. Every source has certain fixed transmission area and associated interference radius, the limiting factors for these parameters of the source are transmission technique and contention level of medium access. The medium access mechanism adjusts the frame length (group of bits are bundled into frames at MAC protocol) to achieve optimal energy level for transmission in given channel state or for assigned BER [10]. Adjustment of parameters like packet length, transmit power and BER will result into perfect harmony of physical and MAC layer protocol of the given network. The protocols suggest that the optimal power of transmission should be related to the length of the packet and also demonstrated that when length of the packet at MAC layer is varied in proportion to the available BER value, the utilization of energy is significantly reduced.

PHY and NET cross layer interaction based solutions: The analysis given by the authors in [11-15], show how physical layer technique affects the working of different routing protocols designed for MANETs. In [16], using propagation model authors have illustrated the negative effects of path loss and shadowing by producing results that are obtained with simple error free model and communication model added with path loss and shadowing. Drastic difference obtained concludes that available state of the channel and the link quality are important factors that affect route discovery and hence hop-count is treated as non-optimal metrics.

The wide diffusion of cross layer interaction proposals in applications of MANETs indicates the popularity of CLD in the research community. The basic questions in CLD approach are: which layers of the standard reference architecture are considered for cross layer interaction? And how to implement intended interaction between identified layers of standard reference? The reasons for asking these questions are: a comprehensive analysis indicating the benefits and drawbacks that suggest the complexity and achievable performance enhancement are not available. Another issue in CLD approach is to how cross layer interaction based architecture and traditional layered model based architecture can coexist with one another. The existing methods for cross layer optimization are normally based on joint solutions which considers three bottom layers of standard ISO reference protocol suite.

V. CONCLUSIONS

In view of future applications, this paper explores the motivations of CLD approach in the context of MANETs. The Investigation of some cross layer optimizations reveals that, CLD enabled MANETs has benefit of designing protocols that are able to adapt as per network conditions and support application with seamless ubiquitous access to distributed resources and service requirements. The protocol's adaptation and mutual cooperation across the layers results in MANET communication that can effectively meet the challenges to be confronted by future applications during coming years.

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AUTHOR'S BIOGRAPHIES

Sadanand R. Inamdar received his Bachelors (B.E.) Degrees in Electronics and Communication Engineering from Karnataka University, Dharwad, India in 1994 and Masters (M. Tech.) in Computer Network Engineering from VTU, Belgaum, India in 2004. Currently he is pursuing his Ph. D. from Research Center, CSE, SIT, Tumkur, Karnataka, India. His general research interests are focused on wireless networking. The major topics include wireless Ad hoc networks and quality of service provisioning within these networks. He has also co-authored several research papers.

Dr. B. Sathish Babu received his Ph.D. in Protocol Engineering Technology Unit, Dept. of ECE at Indian Institute of Science, Bangalore. At present he is working as Professor in Computer Science and Engg. Dept., Siddaganga Institute of Technology, Tumkur. His research interests includes Security in mobile communication, Cognitive agents based control solutions for Networks, Grid Computing, Cloud Computing Scheduling and Security Issues, Big Data, Context-aware Trust issues in Ubiquitous Computing, Privacy issues in WSN, and so on. He has published more than 25 international journal/conference papers in his area of research, which includes Elsevier Computer Communications, John Wiley Journal of Security and Communication Networks, InderScience-Journal of Security and its Applications and so on. He has published a book on Mobile and Wireless Network Security (Tata McGrawHill) in the year 2010.

Dr. Ravi M. Yadahalli is a distinguished academician and professor of Electronics and Communication Engineering with a career spanning over 19 years. He received his Ph. D., Microwave Electronics in 2009. He is an educationist & renowned researcher. He has 16 numbers of publications to his credit both National/International refereed journals of repute. He has guided about 05project/research reports of ME students, and he is guiding 05research scholars for Ph. D degree under VTU, Belgaum, Karnataka, India. Prof. Ravi is reviewer for International Journal of PIER & JEMWA, USA and also, he has reviewed a number of research papers of National and International Conferences.

