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Scalable Adaptive Wireless Networks for Multimedia in the Proactive Enterprise

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Scalable Adaptive Wireless Networks for Multimedia in the Proactive Enterprise

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Index words: wireless networks, Local Area Networks, multimedia, ad-hoc networks, Proactive Enterprise, Scalable Systems, Distributed Network Information Base, cross-layer optimization

ABSTRACT

This paper presents a scalable and adaptive system-level approach to wireless multimedia in the emerging, Proactive Enterprise computing environment. An overview of wireless networks, cross-layer optimization techniques, and advances in wireless LAN technologies is presented. A Distributed Network Information Base with Service Agents at each node is proposed to enable network-wide, proactive adaptation with adaptive routing and end-to-end Quality of Service (QoS) management. The paper suggests that a combination of technological advancements in emerging wireless networks, node-level cross-layer optimizations, and the proposed distributed cross-node system-level architecture are all required to efficiently scale and adapt wireless multimedia in the Proactive Enterprise.

INTRODUCTION

Interactive multimedia on wireless networks requires high bandwidth due to the data rates and payload size [1]. One frequently cited wireless scenario has users conducting real-time, multimedia videoconferencing sessions over a wide-area wireless Internet connection. The wireless client is highly mobile within an enterprise campus or dense city limits and is sharing a media-rich presentation with multiple parties, dispersed in different connectivity scenarios (e.g., home, hotel, or corporate office). The user is experiencing a high degree of QoS supporting the multimedia session and presentation delivery, regardless of his movement or locality. In order for this scenario to occur, multiple effects including time-varying channel conditions, local or remote congestion conditions, and end-to-end QoS requirements must be matched with an adaptive application capable of offsetting the limitations of the network by managing reliability, latency, and throughput degradations while hiding the user from the underlying complexity, degraded QoS, and mobility issues in a wireless environment.

The convergence of wireless networks and the Internet is forging new developments in communication systems and networking services. The rapid evolution of wireless communication technologies is influencing the development of applications, as well as the network services and resources, that will be necessary to deliver traditional voice, data, and emerging media-converged applications, as newer wireless technologies get deployed in the corporate enterprise. Managing service quality and scale across alternative traffic types has long been a challenge in terms of policy-based provisioning and Service-Level Agreement (SLA) management even within the wired infrastructure. These challenges are primarily network administration overhead, limited resources (e.g., network bandwidth) and end-to-end dependencies due to application QoS or mission-critical requirements. With wireless connectivity eventually being more pervasive than physical connectivity supporting the virtual enterprise, these challenges will increase and more than likely create a higher burden on total cost of ownership for Information Technology (IT) managers, based on pre-existing tools and methodologies for provisioning and managing real-time or media-rich applications.

In this paper, we chose to focus on Wireless Local Area Networks (WLANs). WLAN technologies (802.11/Wi-Fi) are targeted to work well within a range of the order of 100 meters. MIMO-based WLAN technologies can use multiple antennas to increase throughput, with the additional capability to trade off increased range for increased throughput. Technologies such as Multiple Input Multiple Output (MIMO) can be applied to other wireless technologies as well. Although WLAN (802.11a/b/g/n) protocols are expected to be the predominant technology for wireless access in an enterprise, future systems in use in the enterprise may have reconfigurable radio technologies and/or multiple radios. WiMAX (802.16a/d/e*) technologies are expected to have a range in the order of several kilometers (< 50 km). UltraWideBand (UWB*) (802.15.3) and Bluetooth* (801.15.1) technologies would be used for short distances (about 10 meters) with UWB technology enabling high data rate wireless transmissions over short distances. Cellular technologies are primarily optimized for voice traffic, and in general, are geared towards supporting long-range but significantly lower data throughput compared to the Wi-Fi-based technologies. Network management and administration techniques used in cellular networks may be applicable in WiMAX and techniques used in wired networks such as Ethernet* (802.3) could also be applied to wireless networks. One could conceive handoff of a mobile user from/to a WLAN to/from other wireless networks such as a lower data rate cellular network depending on the service availability, user mobility, channel conditions, and location constraints. Seamless transfer of multimedia sessions or Voice over Internet Protocol (VoIP) calls between such networks will be an interesting and challenging task in the enterprise in the foreseeable future.

With devices supporting voice, data, and multimedia communications, the unification of voice and data applications will require a higher degree of complexity to untangle end-to-end service dependencies and manage this from within the core network or traditional distributed systems management tools. Policy-Based Management (PBM) has been positioned as a viable technology to provide greater control and management of underlying network resources via the creation and distribution of high-level policies, integrated with the enabling mechanisms of the network infrastructure. As defined in [1], we define PBM as a “unified regulation of access to network resources and services based on administrative criteria.” PBM has been shown to be effective in provisioning QoS, security, and virtual private networks. Nevertheless, PBM is based on a traditional perspective of human administration, similar to many traditional network management tools. In the context of wireless multimedia systems, these systems cannot scale with the time and space varying dynamics imposed by wireless and real-time multimedia systems. In this paper, we argue that, without a systemic shift in how we automate, or in an autonomic fashion, provision and manage rich, multimedia-based services in the wireless enterprise, it is unlikely that a large-scale deployment[1] of multimedia in the wireless enterprise will be achievable. Thus, we propose to move away from the traditional, in-network or administrative means to adapt, scale, and manage multimedia over wireless environments.

In the first section of this paper, we explore options for improved Physical (PHY) and Medium-Access-Control (MAC) facilities to enable capacity improvements in physical and data link layers of the wireless LAN, and we discuss application and transport layer considerations. We present node-level, cross-layer optimizations in the next section and explore opportunities to manage end-to-end state and policies across the layers of the Open Systems Interconnection (OSI) protocol stack. A Distributed Network Information Base is then proposed with Service Agents to enable proactive adaptation for end-to-end QoS management and adaptive routing. Finally, we propose integrating state and policy at all layers of the OSI stack with local, global, and end-to-end services by cohesively integrating in-network facilities with node-level, cross-layer optimizations to achieve multimedia adaptation and scale in the wireless environment.

WIRELESS LAN CONSIDERATIONS

WLANs offer several challenges with regard to multimedia streaming [3, 4, 5]. Dynamic variation in channel conditions due to noise, interference, and path loss effects impact data throughput and packet loss. Dynamic changes in the number of users in the network with their varying data rate requirements resulting in a varying degree of contention and collision in the network impact the amount of bandwidth per user or per flow. Real-time adaptation at the MAC layer is required to adapt to varying conditions. The choice of the transport layer such as Transport Control Protocol (TCP) or User Datagram Protocol (UDP) [1, 5] is also of concern. Multimedia applications have the ability to scale [1] and adapt to varying wireless network conditions, which must also be considered and exploited.

Physical Layer Considerations

At the PHY layer, various modulation and coding schemes are available to a wireless station for transmitting data. Modulation schemes that allow more bits per symbol, help in increasing data rates; however they have symbols closer to each other (in the constellation diagram), and small errors could result in erroneous decoding. Varying code rates can be employed

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* Other brands and names are the property of their respective owners.

* Bluetooth is a trademark owned by its proprietor and used by Intel Corporation under license.

[1] Specifically we are referring to many “point-to-point” or many “point-to-many points” scenarios.

within each modulation scheme to adapt to changing channel conditions by allowing more bits for coding (i.e., lower code rate *k/n*) for more robust transmission as conditions deteriorate. As the code rate decreases, the effective data rate is reduced, and hence the achievable throughput is also reduced. We use the term "mode *m*" to refer to a specific choice of a modulation and coding scheme. The probability, $P_e^m(L)$, of error in a packet of length L bytes (also referred to as the physical layer packet error rate or PER), for a given mode *m*, as a function of the bit error probability p_b is given by equation (1), where the inequality represents the fact that one can recover from bit errors in a packet, due to the coding scheme used at the packet level.

$$P_e^m(L) \le 1-(1-p_b^m)^{8L} \qquad (1)$$

The effective PHY layer throughput can be then expressed as $T_{PHYm}(x) = A(1-P_e^m(L))$. For a given mode *m*, $T_{PHYm}(x)$ and $P_e^m(L)$ can be approximated with sigmoid functions [6] of the form

$$T_{PHYm}(x) = A/(1+e^{-\lambda(x-\delta)}) \qquad (2)$$

$$P_e^m(L) = 1/(1+e^{\lambda(x-\delta)}) \qquad (3)$$

where x is the SINR in dB, and $y = T_{PHYm}(x)$ is the throughput in Mbps. Link adaptation schemes are used so that a user adapts and operates in a region on the throughput curves where the PER is low. When P_e is small, $log(P_e) = -\lambda(x-\delta)$. Game theoretic formulations could be used to develop optimization techniques for multimedia adaptation by using such sigmoid mathematical modeling as described in [6, 7]. PHY-level throughput versus Signal to Interference+Noise Ratio (SINR) curves are shown in Figure 1 for 802.11a/g networks. The max PHY-layer throughput of 54 Mbps is obtained in the 64 QAM, rate ¾ mode.

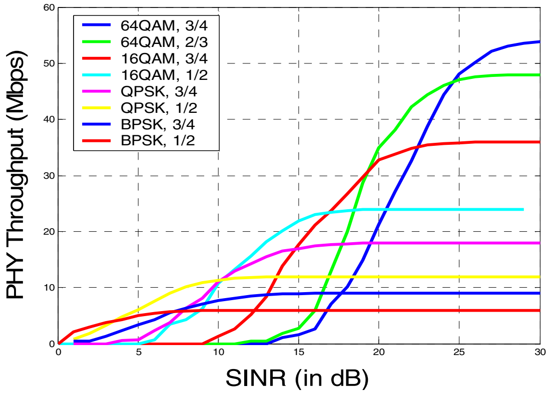

Figure 1: PHY throughput for 802.11a/g networks

MIMO for Improved PHY-Layer Capacity

Multiple transmitting antennas [8] can help increase the data rates in the same channel. Multiple receiving antennas can help in efficient recovery of the transmitted data. Multiple antennas can also be used to increase range and reliability of data transmitted in a channel without an increase in data rates. Alternatively, one could increase data rates using multiple antennas by transmitting data in multiple channels simultaneously.

With two transmit antennas (typically in a 2x3 MIMO configuration with 2Tx antennas and 3Rx antennas), one can expect a throughput of 108 Mbps [5] in a 20 MHz channel. Using a wider 40 MHz channel, as opposed to a 20 MHz channel can increase the throughput to 216 Mbps. With four transmit antennas, the throughput can increase further to 432 Mbps. Using additional Orthogonal Frequency Division Multiplexing (OFDM) sub-channels and/or using newer coding schemes such as Low-Density Parity Check (LDPC) codes approaching the Shannon limit, could increase the throughput to over 500 Mbps in future WLAN systems. These improvements in overall PHY-layer capacity are being pursued in the 802.11n standard.

MAC Performance Considerations

The effective throughput at the top of the MAC is further reduced due to a number of factors [5, 7, 9, 10] such as the number of current users in the network medium, user requirements, priorities, retry-limits, and link adaptation schemes used, channel conditions based on noise and interference, backoff counter depths, backoff stages, protocol timing, and header overheads, and also, the amount of additional time that the medium is unused/idle. The overall throughput is also affected by the transport mechanism used (TCP/UDP/UDP-lite), and by whether there is additional application-layer redundancy such as Forward Error Correction (FEC) across packets being used. In general, the overall throughput as a function of the SINR continues to assume a sigmoidal form with a reduced maximum asymptotic value for the throughput.

MAC Throughput Considerations

The throughput at the top of the MAC is affected by the following:

1) The PHY-layer throughput. (The PHY-layer throughput depends on the PER at the physical layer and the transmission duration for each packet, which in turn is a function of the modulation and coding scheme used during transmission.)
2) Protocol timing overheads such as interframe spacings, and acknowledgement time.

3) Time spent in the random backoff counter (the value range increases exponentially with transmission failures).
4) Time during which the medium is busy with other users transmitting.
5) Unused idle time in the network.

For example, in a 54 Mbps PHY mode in an 802.11a WLAN, including protocol overheads, the ideal MAC throughput is approximately 30 Mbps, and one may obtain a throughput of only 24 Mbps in a typical WLAN. Since only one user transmits at a given time using the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol, the available bandwidth for a user can be considerably reduced depending on the data rate requirements of other users in the same network.

Packet Errors and Retransmissions

Retransmissions are attempted at the MAC layer in the absence of an acknowledgement. Packets may be in error if the acknowledgement is not received from the destination within a specified duration after transmission. Either the packet may be in error when it reaches the destination or the return acknowledgement might itself be in error. In both cases, a packet is retransmitted by the MAC, as long as the retry-limit is not reached. During retransmissions, link adaptation may be performed to attempt sending a packet in a more robust modulation and coding scheme. Queue backup in the transmit queue at the MAC layer can impact performance. Jitter and delay requirements may impact how many retransmissions should be attempted before further packet retransmission attempts are discarded. If a reliable transport mechanism such as TCP is used, then retransmissions at the MAC layer should be preferred as MAC-level retransmissions have significantly less overhead compared to retransmissions attempted from the transport layer. Additional overhead at the MAC layer occurs due to collision with other users in the CSMA/CA protocol. To avoid collision, an exponentially increasing backoff counter is used, which can cause increased overhead.

Link Adaptation

The desired behavior for link adaptation to determine the optimal choice of the modulation and coding scheme to use is depicted in the “hysteresis loop” in Figure 2. Here OOP represents the Optimal Operating Point [6] for a given choice of the modulation and coding scheme. (In this figure the throughput functions are zoomed in for two modes.) The throughput improvement becomes reduced beyond the KNEE [6] (point of maximum curvature on the sigmoid), and, beyond the OOP, the throughput only improves marginally. The Adaptation Switching Point (ASP) denotes where it can become advantageous to switch to a different modulation and coding scheme. As the network conditions change, the OOP will dynamically vary for each wireless station. It can be difficult to distinguish between foreign interference, collisions, and noise. The effectiveness of the adaptation is limited by the rate at which the channel changes (including activity of other devices) and how fast the algorithm adapts (limited by the integration period over the metrics used for adaptation).

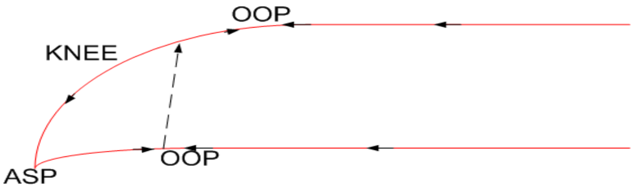

Figure 2: Hysteresis Loop for adaptation

In general, more robust modes are used (less bits per symbol or more coding) when channel/link conditions are degraded. However, these more robust modes take longer to transmit the same amount of data, which reduces throughput.

802.11e Protocol Improvements

The 802.11e protocol is designed to optimize QoS in a wireless network. Two service classes are suggested: QoSNoAck and QoSAck. The QoSNoAck mechanism may not be very useful as it is typically desirable to attempt retransmissions at the MAC layer. There are four access categories (Voice, Video, Best Effort, and Background) and eight user priorities (two for each access category). The access point configures the MAC-level parameters such as the contention window size (CWmin/max), the interframe spacings (AIFS), and the transmission opportunity (TxOP) duration. Reducing the contention window size allows a transmission to be attempted sooner with reduced backoff. Reducing interframe spacings reduces protocol overhead. Increasing the transmission duration allows more blocks of data to be sent in sequence with the same TxOP duration. A block acknowledgement can indicate the correctly received blocks so the blocks in error can be retransmitted during the TxOP duration. The Wi-Fi Multimedia (WMM specification) implements the Enhanced Distributed Channel Access (EDCA) contention-based access mechanism suggested in 802.11e with the access priorities. The Wi-Fi Multimedia–Scheduled Access (WMM-SA) specification provides support for HCCA-based centralized scheduling in addition to EDCA. The Hybrid-coordination-function Controlled Channel Access (HCCA) mechanism allows for bandwidth to be dedicated to a specific transmission in a contention-free period. All stations admitted with dedicated bandwidth in the contention-free period complete their transmissions and then the rest of the stations contend for access using

EDCA during the contention period. Multimedia applications that need guaranteed time on the medium may use the HCCA mechanism to access the medium. The overall 802.11e specification is expected to include the WMM and WMM-SA specifications, and to support additional features such as Block Acknowledgements, Automatic Power-Save Delivery (APSD) capabilities, and Direct Link Setup (DLS) for peer-to-peer (P2P) communication.

802.11n MAC Enhancements

MAC-layer enhancements are being suggested in the 802.11n standard, to supplement the improved capacity with MIMO in the PHY layer. One key enhancement is to enable aggregation of several MAC-level protocol-data units into a single PHY-layer protocol data unit. This enables a longer packet to be sent relative to the protocol timing overheads associated with the WLAN transmission. Block acknowledgements specifying the correctly received portions of the aggregated message are used. Receiver feedback to a sender for improved link adaptation at the sender is enabled. Reverse direction data flow can be used by a receiver to use available transmission time to transmit data to a sender in conjunction with an acknowledgement. These optimizations can further help to improve application performance and scalability in a wireless environment.

Application/Transport Layer Considerations

UDP is cited as the preferred transport mechanism [1, 4, 5] for video and audio streaming. TCP can incur increased delay and jitter with TCP's congestion-avoidance mechanism and re-transmission [1, 5]. Application-layer FEC [3, 4] between packets over UDP could be used to compensate for lost packets at the MAC layer, with error-concealment strategies [1] used at a receiver to mitigate the effect of packet losses. One needs to exploit scalability in multimedia representation and identify the most important information to communicate given the available conditions. Application and MAC-PHY cross-layer optimizations [4, 7] and joint source/channel coding [3, 11] can help in adapting to optimally transfer the most relevant information over the wireless channel in response to current channel conditions.

The video quality can be represented, in general, using the rate-distortion model $D_e = \theta/(R_e - R_0) + D_0$, that was suggested in [3]. However, for the range of operation and the SINR values required to make decisions, the video quality Q (i.e., PSNR) could be approximated by a linear equation (or piece-wise linear) [7] of the PER P_e of the form $Q = -\mu\ (P_e - \rho)$. The choice of the adaptation mechanisms at the multimedia algorithm level can influence the value of μ. If P_e is small, then we can assume $\log (P_e) = -\lambda(x - \delta)$. Therefore $dQ/dx = \mu\ \lambda\ P_e$. Thus, one can study the variation in video quality as a function of the varying channel conditions and establish correlation between conditions at the physical layer to perceived application performance. This suggests that one could consider direct cross-layer interactions between various layers in the protocol stack to proactively optimize multimedia performance in a wireless environment.

NODE-LEVEL PROTOCOL-STACK CROSS-LAYER OPTIMIZATIONS

Cross-layer optimizations in ad-hoc wireless networks [12, 13] have been proposed for direct cooperation between layers in a protocol stack to achieve optimal performance. Recent research in the area of streaming wireless multimedia has focused on cross-layer optimizations [4, 7] in the protocol stack at each node. Such optimizations include link adaptation at the MAC layer, retry-limit adaptation at the MAC to compensate for packet errors, application-layer FEC to compensate for packet losses at the MAC, traffic reshaping to handle varying bit rates, dynamic resizing of buffers, management of arrival and departure rates into queues, reducing end-to-end delay and jitter to meet real-time requirements, adaptive modulation schemes to use more robust modes for base layers, joint source-channel coding, channel reassignment under worsening conditions, and the use of more robust modulation and coding schemes for interference tolerance. This node-level adaptation is done quickly with interaction between key protocol layers such as the application layer, the MAC layer, and the PHY layer based on the knowledge of the current conditions in the network. The scalability inherent in multimedia representation helps in adapting to such dynamically varying constraints. Additional optimization could use light-weight communication information exchange to indicate degradation in battery availability for mobile devices, and in memory availability with other simultaneous tasks needing to be supported in the system. Such information can be useful for the two end points to adaptively reduce processing requirements in terms of frame size and frame rates and hence minimize energy utilization. This would extend the duration of a multimedia application such as a video conferencing session.

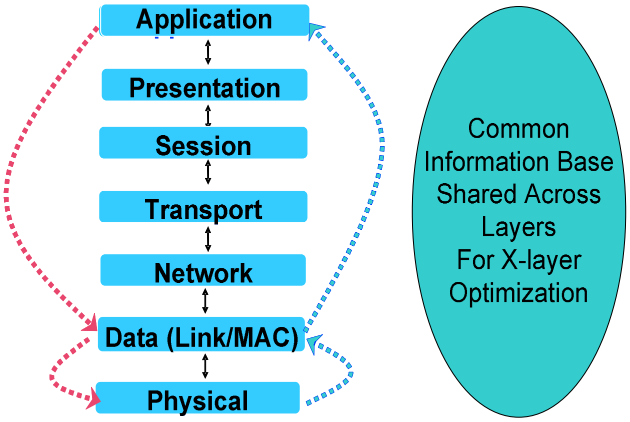

Figure 3: Node-level application-MAC/PHY x-layer optimization

Figure 3 shows cross-layer optimization between the application and MAC/PHY layers with direct exchange of information between the layers, and adaptation feedback between the layers. A common information base can be used to share information between layers. The action to be taken is determined by the layer that owns the action, based on feedback from the various layers.

With direct interaction between the layers, each layer can adapt proactively with the most current information in the layers. If channel conditions degrade, and if such information is made available to the application layer much sooner compared to information propagation through the protocol stack, then the application can proactively adapt based on current conditions in the network. Likewise decisions at the MAC layer can be proactively taken to prioritize scheduling or selective transmission of information over the channel, based on current channel conditions.

SYSTEMS ARCHITECTURE FOR WIRELESS MULTIMEDIA SCALABILITY AND ADAPTATION

To support a horizontal (end-to-end) and vertical (node-level) systems orientation to scale and adaptation of wireless multimedia, we believe the end-to-end principle [14] and in-network control must converge. The ability of applications to adapt to positive or negative changes in wireless conditions, by either leveraging in-network services or binding alternative node-level, inter-layer optimizations, will give applications greater flexibility in managing real-time or media adaptation within a wireless environment. We therefore call for tighter layer integration and automation of application control and bandwidth management. The application's adaptation flexibility will depend on its ability to detect or respond on a much faster time-scale (e.g., to support fast handoff), thus requiring the application to cooperate with the transport layer's congestion control loop. Alternatively, the necessity to manage the wireless channel bandwidth will depend on the clocking rate and control mechanisms being used by the application or session layer to control the incoming rate of the flow; sharing knowledge or policies between these layers can further increase their cooperative effectiveness. Additionally, we view existing layered or component services (e.g., application-layer FEC, TCP congestion/flow control, 802.11e, IP Differentiated Services) coordinating functions of congestion management, service differentiation, bandwidth management, and reliability to achieve a higher degree of local system optimization.

We propose broadcasting or multicasting system-level information in smaller-scale, tightly coupled networks, or direct exchange of information between nodes with information propagation when required. Such system-wide proactive adaptation and management of resources real-time can ensure that the system is made more aware and resilient to dynamically varying constraints, ensuring that the impact of worsening conditions is minimized or that the best option is taken during improved network conditions. Further, we propose using direct peer-to-peer transmission after establishing contact between peers, if the direct peer-to-peer wireless link is good and if direct communication between peers is enabled. Alternatively, one may have to use multiple hops over short distances to reduce packet errors due to path loss over large distances in wireless links. However, hops over the same frequency channel can cause contention, which can reduce available bandwidth. In multihop networks, one has to be concerned with both exposed nodes (in the sender's range but out of the range of the destination) and hidden nodes (out of the sender's range but within the range of the destination). The network configuration between two endpoints may vary dynamically depending on varying network conditions, mobility, or other constraints in the system. QoS policy or state information exchange through intermediate nodes is also necessary to meet end-to-end requirements.

In large wireless ad-hoc networks, routing tables with link information can grow significantly in size [15]. This information could include link quality information as perceived at the MAC/PHY layer at a node. To achieve scalability, nodes should store only local information about nearby links (such as information about links that are only one hop or two hops away). This information stored in a distributed fashion can be propagated through nodes on request, to understand end-to-end performance on a communication path between two endpoints in the network. The response time of adaptation mechanisms at the nodes based on these dynamically varying conditions will determine how effective and proactive the adaptation mechanisms are, to ensure that any variation in the quality of the received multimedia transmissions is imperceptible to the user.

Systems Approach

The adaptive techniques at a single node are not sufficient to address overall scalability issues in the wireless or hybrid wireless and wired enterprise networks. To address end-to-end QoS, we must extend the cross-layer optimization techniques to address constraints and issues in the network and across the enterprise to provide additional system-level feedback and more intelligent adaptation in the protocol stack at respective nodes in the end-to-end path. Optimizing overall end-to-end QoS requires knowledge or state of key elements of the network system or the communicating session. This knowledge must also be shared effectively between these elements. The optimization across the network will be required due to variations in link conditions and user mobility constraints in the wireless environment. Current conditions at the MAC and PHY layers can be propagated to the network layer at each node, and joint optimization between the network and MAC layers can be used, in conjunction with network-wide information, to optimize routing and end-to-end QoS dynamically in the network as depicted in Figure 4.

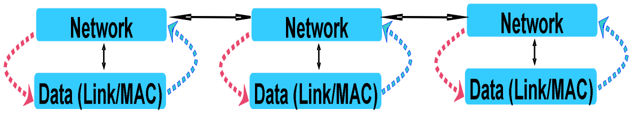

Figure 4: Joint optimizations between the IP layer and the Data (Link/MAC) layer across nodes for adaptive routing and end-to-end QoS management

Network-wide adaptation can be proactively achieved, with fast exchange of information about individual links between two endpoints to assess end-to-end performance in the network. The PHY-layer conditions on each link in a wireless network can dynamically vary due to several factors such as network congestion with other users, interfering signals and noise, and the path loss associated with the link. The optimal path between two endpoints in a network would be a function of the quality of each of the links on the path between the end points. With dynamically varying constraints in a wireless network, a statically configured optimal path may soon become a less optimal one. Alternate paths for communication of information can be proactively established to quickly switch to the best alternate path, as conditions vary over time in the system.

We propose a Distributed Network Information Base (DNIB) with query management for retrieval of end-system-level or network node-level knowledge or information. A DNIB Service Agent (DNIB-SA), as illustrated in Figure 5, will be available at each node to respond to requests for information from a neighboring node in the network. The DNIB-SA will respond with information available from the DNIB content locally available at the node, and, if necessary, the agent will forward the request to one or more neighboring node(s), until end-to-end information between two end points involved in the communication is obtained. The DNIB content, locally available at a node, could consist of information about a node and recent information about neighboring nodes (based on the depth–number of hops–of the routing table maintained at the node). Request forwarding is done selectively to nodes that are more likely to be candidates for the communication path (based on link quality, link utilization, and node-location information, if available) between two end points. During request forwarding, a list of visited nodes is maintained to avoid loops, and information gathered is propagated back to the end points.

The DNIB-SA should monitor conditions on links being actively used in its routing table. Network conditions on active links in an active route can vary due to user mobility or due to changes in link quality or link utilizations. For an active critical weak link on which conditions may be degrading, the DNIB-SA will quickly propagate information about dynamic variation in network conditions to the nodes on the active route, to eventually propagate the information to the end points on the active route. This will enable proactive end-to-end QoS management between endpoints involved in communication, with real-time adaptation. Additionally, a subset of DNIB-SAs corresponding to nodes in an active route could dynamically reconfigure an alternate route in a sub-network. Local routing tables will get modified to reflect the new active end-to-end route. End-to-end QoS information for the newly chosen route will be propagated to the endpoints.

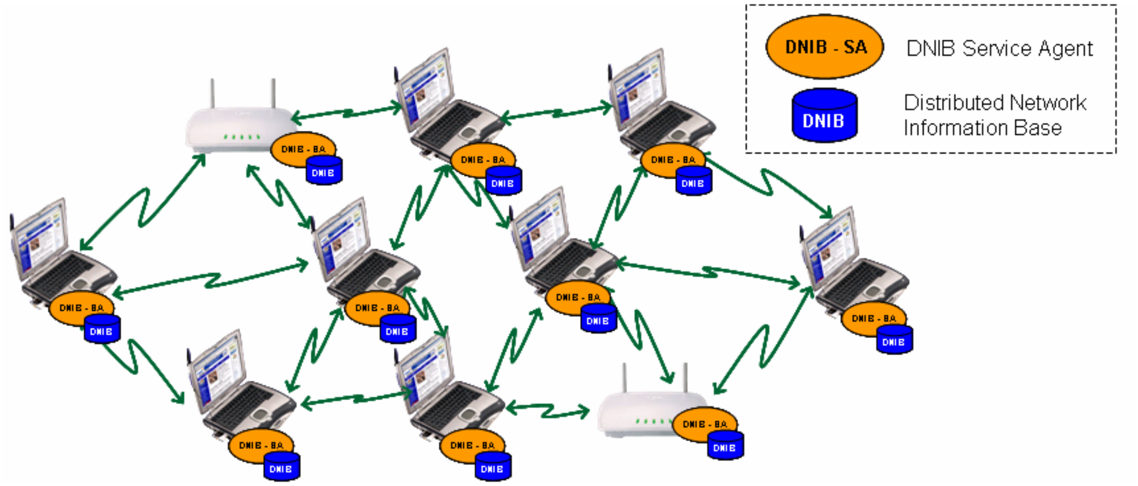

Figure 5: DNIB Service Agent distributed configuration

To summarize, DNIB-SAs have the ability to perform the following tasks.

1) Respond to requests from neighboring nodes.
2) Monitor conditions on active links in active routes and forward information about dynamic variations in link quality to nodes in the local routing table at a node, with information to be propagated quickly to endpoints in a communication path to enable real-time adaptation.
3) Change policies that can relate to routing, QoS, or security as needed. In addition, depending on local, global or end-end situations, the policies could relate to changing flow transport parameters or changing monitoring requirements.
4) Change network configuration and enable localized route modifications when required by collaborating with DNIB-SAs in a sub-network to configure an alternate route when conditions on a link degrade.
5) Propagate end-to-end information to endpoints for a newly configured route.

Finally, we suggest partitioning the control system across three layers of resource control hierarchy. We believe that this is necessary to achieve autonomous control on a global level, a local level, and a flow level; each of which is directed at a different set of objectives (e.g., global usage efficiency, local access maximization and fairness, and end-to-end flow control and adaptation), but overlapped on their influence on the wireless channel resource.

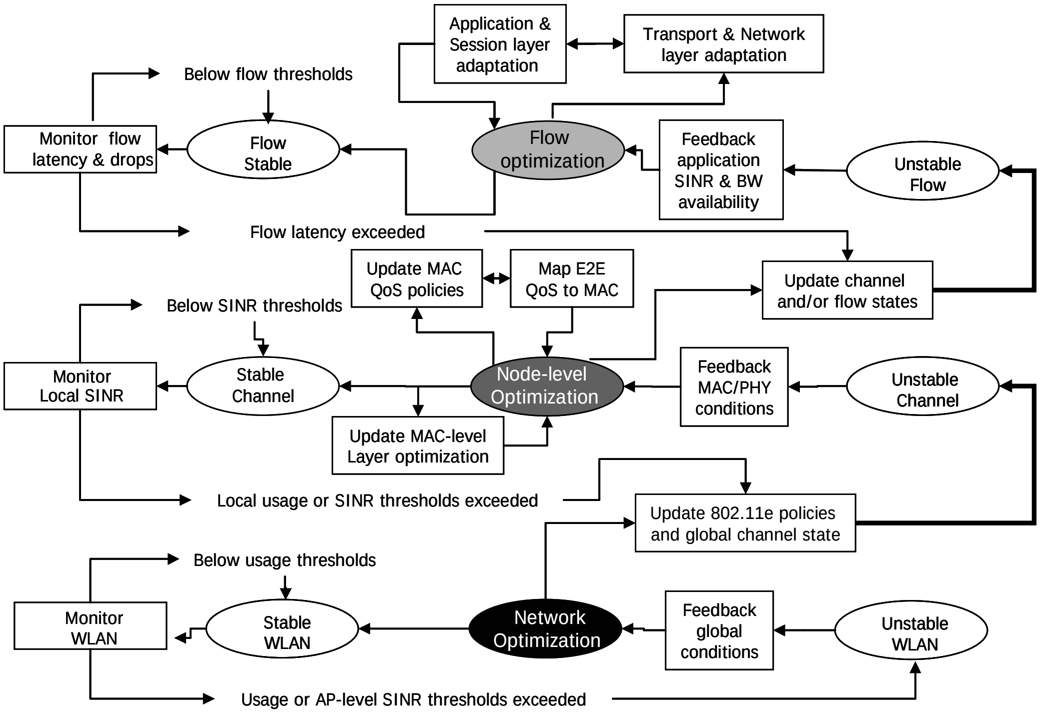

Figure 6: Distributed State Machine

As illustrated in Figure 6, three autonomous levels of feedback-based control are supported in the proposed Distributed State Machine (DSM) [16]. At each level, a stable and unstable state exists, while an operational state is centered between them to represent the control state. Also at each level, a monitoring procedure checks against stability thresholds to determine the possibility of instability and the need to enter into a control state, invoking alternative algorithms, which manage the particular level of concern. At the global and local level, policy changes will cause the state machine to enter into an unstable local channel state or unstable flow state, respectively. Multiple instances of the state machine procedure will run; one per wireless node and one for each of the flows running within the wireless environment. The flow procedure is essentially part of the normal transport process supporting both congestion and reliability control for each session flow. However, we expose it here as a necessary integration aspect of our systems framework. Also shown at the local and flow level is a procedure to update the respective layers of the stack on specific bandwidth availabilities and SINR state, respectively. This multitier DSM approach does not suggest these three (i.e., state machines) threads as being independently managed or controlled. Instead, they must be cooperative and autonomic; policies and states for their operation are exposed or exchanged for the intended stability and balance of the system operation. To achieve this, we consider the cross-layer optimization framework, where layered services cooperate through exposed interfaces for binding purposes, dynamic configuration, or state management. Furthermore, we can have greater control over the stability and efficiency of the system by enforcing policy controls at different timescales as needed to react, maintain, or be proactive, as warranted by the wireless device, the application flow, or the wireless channel.

To summarize, an overall systems approach is proposed with three major elements:

1) Adaptive capabilities to reconcile network delivery requirements and state management on a local and end-to-end level.

2) Distributed information base at a cross-node level and network-wide level, for adaptive scalable routing and dynamic end-to-end QoS management. Information propagation is suggested using point-to-point, broadcasting, or multicasting communication mechanisms.

3) A three-level DSM supporting closed-loop control and management is suggested with interactions between the three levels (flow, node, and network levels).

CONCLUSION

In conclusion, an alternative approach to traditional methods is recommended for provisioning and managing a scaleable media rich, mobile, and dynamic proactive enterprise. This paper proposes a system-wide, cross-node, cross-layer optimization architecture to scale the number of multimedia users, audio/video streams, and varying multimedia bandwidth requirements, while cognizant of competing mission-critical traffic and aggregate demands on network resources. A Distributed Network Information Base with Service Agents at each node is proposed for adaptive routing and dynamic end-to-end QoS management. Combining node-level, cross-layer optimization architectural enhancements, end-to-end flow, and network-wide feedback and optimizations, we have proposed a closed loop, multitier resource control and management system architecture to enable self-manageable multimedia adaptation and scalability.

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