COGNITIVE MANAGEMENT ARCHITECTURE FOR COMMUNITIES OF WIRELESS DISTRIBUTED NETWORKS

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Abstract--*Wireless distributed networks (WDNs), which includes wireless ad hoc networks, have experienced explosive growth in research, development, and commercial deployment. However, the ability to independently deploy and operate a wireless distributed network creates significant challenges in effective service delivery when several networks are deployed in the same area Techniques such as cognitive radio networking address spectrum sharing, but other issues, such as security and quality of service are open problems. We propose a cognitive management architecture for communities of wireless distributed networks to optimize performance and create service guarantees for the community as a whole. In this paper, we describe the management architecture, outline the salient features of the major components, and discuss the research challenges.*

Introduction

Wireless distributed networks (WDNs) are poised to become the next wireless networking platform to experience explosive growth in research, development, and commercial deployment. WDNs are independently deployable, limited range wireless networks that provide flexible and adaptable platforms for personal, local and metropolitan area communications, and include wireless (and mobile) ad hoc networks, mesh networks, and wireless sensor networks. These networks require very little infrastructure and share unlicensed radio spectrum, making them very desirable for a wide variety of fields, such as environment monitoring, battlefield communications, and disaster recovery, as illustrated in Figure 1(a). However, the ability to independently deploy and operate a wireless distributed network creates significant challenges in effective service delivery when several networks are deployed in the same area. We refer to this scenario as a *community of wireless distributed networks*, or a *WDN community*. A WDN community has unique challenges, in that the networks must compete for the same set of resources. The lack of coordination between neighboring WDNs results in a tendency to act counter-productively (e.g., create unnecessary interference or transmit at unbalanced power levels), to create vulnerabilities to misbehaving participants (e.g., allow security attacks or bandwidth drains), and to limit the ability to offer quality of service guarantees.

A large body of research addresses problems in a stand-alone wireless ad hoc network, such as

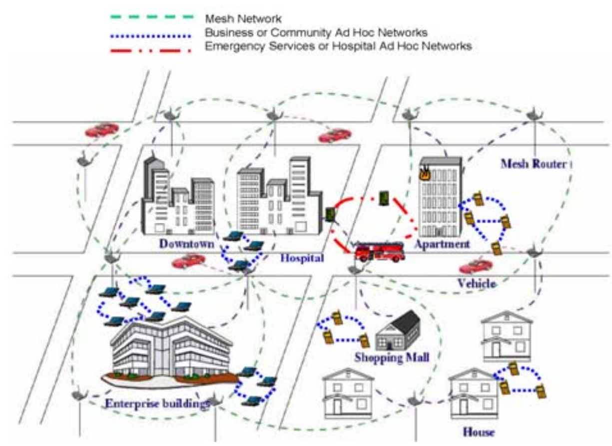

Figure 1. Community of wireless distributed networks

routing protocols, medium access control or security protocols, and cognitive radio techniques are being designed to coordinate the use of wireless spectrum, but there are few attempts to manage the "unmanageable" issues for communities of WDNs. Without some level of management for communities of WDNs, networks will remain vulnerable to sporadically incoming and outgoing networks, bandwidth surges and dives, pockets of interference, malicious nodes, and other challenges. Even adaptive radio spectrum techniques, such as software radio, are not effective until some level of guidance can be provided. This research effort seeks to develop an architectural framework that would allow a community of WDNs to be managed and the behavior of its constituent wireless networks influenced to optimize community performance.

Cognitive Management Architecture

The cognitive management approach refers to the combination of observation, orientation, decision, and action processes to learn and adapt to the communications environment [1],[2]. A cognitive management network has an intelligent process that can perceive current conditions and then plan, decide, and act on those conditions. The network can learn from these adaptations and use them to make future decisions, all while taking into account overall network goals. A cognitive management network requires a software adaptable network (SAN) to modify aspects of the network behavior, where the SAN is simply one or more tunable network elements. For example, a cognitive radio, which functions as the intelligence that lets a software defined radio determine which mode of radio operation and radio parameters to use, could be a candidate SAN element. The difference in the two is that a cognitive network concerns the entire network operation and goals and considers a variety of reconfiguration options, crossing all of the OSI layers, which may include modifying transmission power levels at the physical layer, modifying transmission schedules at the medium access layer, modifying routing behavior at the network layer, or modifying authentication key distribution at the application layer. The cognitive management approach also builds on the study of cross-layer optimization, which is designed to communicate information between different layers of the network protocol stack to perform global optimization algorithms. While cross-layer optimizations often focus on a single parameter's performance and neglect other factors of the overall system, the cognitive management architecture is planned to have a wider breadth of options that are available to an intelligent network, as well as a global networking perspective.

The cognitive management architecture is shown in Figure 2. It includes three components: (1) an overlay sensor network for monitoring and observation, (2) a policy based management infrastructure for recording, evaluating, and implementing policy, and (3) a network of actuators, called policy enforcement points, for influencing network reconfiguration. The function of each component is described below.

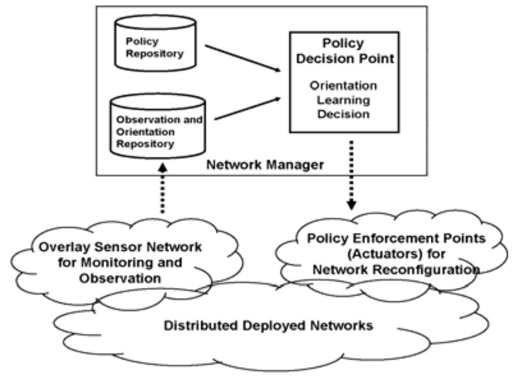

Figure 2. Cognitive Management Architecture

Overlay Sensor Network Monitoring is most often viewed as an application of a wireless distributed network, such as a wireless sensor network, rather than as a service to a WDS network. However, to provide management functions to a community of WDNs, there is a need to collect information regarding the current state of the parameter to be managed. The system must be monitored to collect statistics on all levels of the protocols stack, such as radio channel conditions, interference levels, packet dropping rates, packet transmission rates, transmission power levels, etc., in order to help adapt to device behavior that will optimize overall community performance. In the wired network, or in the infra-structured wireless network, performance data is steadily collected in by backbone network. Network monitoring among wireless distributed networks has a much greater impact on resources. The proposed network monitoring system must function as an independent observer that can measure and interpret the conditions of the network, with minimal participation from the communicating nodes.

Policy-based Management Infrastructure The cognitive management architecture can exist as an integrated component in a wireless network or as an external overlay network that provides management services. The external manager approach allows for transportability, as well as a wider application to many distributed system scenarios. An external service limits the impact on the resources of the subscribing networks, except for pertinent information exchanges. In addition, an external manager allows for multiple networks to be monitored simultaneously, so that the resource expense is shared among distributed wireless networks in the same area. We envision the cognitive network overlay to be part wireless ad hoc network and part wireless infra-structured network. This may include either a hierarchical structure, where information is reported and processed at different levels, or a flat structure, where all information is reported to a single controller.

The backbone controller has the responsibility to consolidate, process, and make decisions based on the information being received from the wireless networks. Once the information is gathered by the observers and relayed to the network manager effective metrics should be available to provide inputs to the decision making process. For example, if low bandwidth is an issue, policy-based evaluators must determine if the low bandwidth condition is transient, if it is being created by control packets versus data packets, or if it is being created by an earnest user versus a bandwidth “hog” versus a malicious user attempting a denial of service attack, and assign weights to each case. In addition, optimizing network performance must occur in consideration of the communities of networks. Beneficial changes to one network, such as an increase in transmission power to reach isolated devices, may result in catastrophic changes to a neighboring system, such as an increase in interference levels that prohibits communication. Thus, policy-based evaluation of the monitoring information must occur within a regional and global context and must consider inter-related factors that will allow the community as a whole to experience better performance.

Policy Enforcement Points Opportunities for influencing WDN behavior fall into two categories: (1) information exchange, and (2) triggers for reconfiguration. Information exchange involves the insertion of messages into the resident WDN protocols in order to bring about a change in behavior. For example, to insert modified link weights into a routing protocol, or to initiate an authentication key change in order to isolate a suspected malicious or breached node. Triggers for reconfiguration are more device-driven, and require study at the device level, as well as at several layers of the OSI protocol stack. There are a wide range of reconfigurable parameters for a WDN, as well as developments in software radio that will allow reconfiguration of the physical layer parameters of the device. The impact of the optimization of one parameter must be balance against the impact on the other parameters in the same network, as well as the impact on the other WDNs in the same area. Adjustments may need to be made in order to ensure rapid response to problems in the WDN, as well as latencies incurred by the various techniques. Finally, the processing power and computational abilities must be taken into account.

Conclusion

The goal of this research is to enable wireless ad hoc networks to be independently deployed and operate in the same area, while maintaining effective service delivery. While cognitive radio addresses spectrum management, the cognitive management architecture for wireless distributed communities provides a better solution for performance optimization of the community as a whole

Acknowledgements

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