Enabling Fast Reliable Notification over Multi-Networks

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1. Motivation

Our work focuses on alerting and notification systems that support reliable dissemination of critical information to a large number of receivers within a very short period of time. Such rapid alerting is used in many contexts – it is especially useful in the event of a natural or man-made disaster where information must be rapidly delivered to the affected population in order to reduce the impact of the unpredictable disaster. It is also relevant in military command and control scenarios where timeliness and reliability of communication is of the essence. Over the last few years, we have developed an understanding of the key factors in scalable information dissemination to large populations (http://www.ics.uci.edu/~projects/dissemination) and designed technology innovations to convey accurate and timely information to those who are actually at risk (or likely to be), while providing reassuring information to those who are not at risk and therefore do not need to take self-protective action. At the delivery layer, we are developing extremely fast and reliable protocols for delivery of short warning messages (e.g. an earthquake early warning) and richer alerts (e.g. maps) over wired and/or wireless networks. At the content level, our emphasis is on enabling customizability of the alert message via a distributed publish/subscribe paradigm[JMV08, JHM08, JMV09,JHM09]. In this paper, we highlight some of the key research thrusts we are exploring at the delivery layer and describe our efforts to develop a system that disseminates information over multi-networks. Such a multi-network is dynamically constructed in temporary settings and circumstances by mobile nodes connecting to the network backhaul through gateways (i.e. routers that connects to the external backhaul), and is able to support information flow in and out of the construction site through the gateways.

2. A Suite of Notification Protocols

The whole process of notification in events can be divided into three phases; the pre-event (early warning), trans-event (ongoing during the event) and post-event phase. Deployment of dedicated infrastructure for warning that is operational and available 24/7 is unlikely due to a variety of reasons – cost, deployment feasibility etc.. The key challenge in the pre-event phase lies in delivering this message rapidly (within a short period of time), scalably (reaching a large number of recipients), reliably (despite network outages and message losses) and efficiently (low operational cost during non-event times with quick ramp-up when needed). The message content can vary significantly and may contain images, small voice/video clips and GIS data that range in size from KBs to a few MBs. Impacted populations, i.e. recipients, are often very widely distributed and use multiple access technologies to receive the information (e.g. email, telephony, SMS). The generation and dissemination of personalized, rich alerts to a large number of recipients poses additional challenges. Our prime approach to address these challenges is through the design of middleware solutions that exploit knowledge of (a) application and user needs and (b) device and network constraints to design cross-layer solutions that capture tradeoffs between timeliness, reliability, information quality for diverse application data (e.g. short text message, large image) over heterogeneous wired and wireless networks. We present some sample research efforts below.

Fast Reliable Application Layer Multicast (Pre-event Notification): In relatively static environments (e.g. where nodes do not move), a natural approach to reduce redundancy in dissemination from a single source to a large number of receivers is to use application layer multicast (ALM). Here, an ALM server node can use network/overlay topology information to construct an tree structure for disseminating messages efficiently (i.e. with low redundancy). In heterogeneous environments, constant availability of nodes in the ALM structure cannot be guaranteed – nodes may join/leave the system dynamically or might be engaged in other processing when the warning is instantiated. To support reliable dissemination, traditional ALM techniques use time-consuming ack-based failure detection/recovery, which cannot be used when warning times are short. To guarantee fast, reliable, and efficient dissemination, we propose FaReCast, an ALM protocol that exploits multiple data paths between nodes judiciously via (a) a forest-based M2M (Multiple parents to Multiple children) ALM structure where each participant node has multiple parents as well as multiple children and (b) a multidirectional multicasting algorithm that effectively utilizes the multiple data paths in the M2M ALM structure. In addition to top-down communication, the multidirectional multicasting algorithm deploys bottom-up and horizontal data flow carefully. Our initial simulation studies indicate that Farecast is able to provide very high reliability (99%) despite significant failures while meeting the timeliness needs of message delivery.

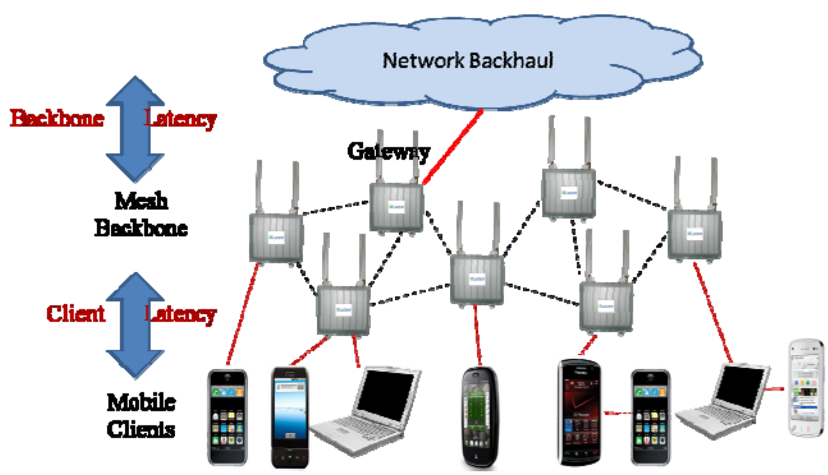
Flash Dissemination of Rich Data (Trans Event Notification) : Given the unpredictability of resources in the trans-event phase, our approach is to exploit any and all available resources for alert dissemination. Our work specifically focused on enabling flash dissemination (very fast dissemination to a large number of users with little warning time) in peer-oriented networks where nodes that receive the alert participate in the dissemination process. While traditional gossip-based broadcast systems are designed to accommodate unpredictable faults, they face scalability issues and do not deal well with node/network heterogeneity. Using the P2P paradigm, we developed techniques for fast dissemination of rich information over heterogeneous peer-oriented networks that are subject to unpredictable conditions of load and failure. One such protocol, CREW (Concurrent Random Expanding Walker) **[**DVM06] [DXL06] is a fully decentralized, gossip-based protocol, that reduces data overhead and increases both inter and intra node concurrency. Increased concurrency and reduced overhead allows CREW to disseminate data very fast and to scale in terms of both network and content size. To address catastrophic failures in the P2P network where a large percentage of the participating nodes in the peer network fail simultaneously, we developed a new protocol (Roulette) [DAC07]. Using the Roulette protocol, we built Flashback, a scalable distributed web server.

Data Dissemination over MANETs (Trans Event Notification): Our research in information dissemination over mobile adhoc networks ([XDV07,XMV09,XSV09,XSV09a])can broadly be classified into – (a) instantaneous dissemination in connected networks and (b) delay-tolerant dissemination when network endpoints may be disconnected or intermittently connected. Specifically, we have worked on providing reliability guarantees for broadcast of data with rich content over connected wireless ad hoc networks. Existing approaches to reliable wireless dissemination often assume network size knowledge, or that receivers know about the dissemination in advance, and that applications have uniform reliability needs. To accommodate the varying reliability needs of dissemination applications, we developed the RADcast (Reliable Application Data broadcast) protocol that integrates : (a) techniques to ensure that receivers obtain the dissemination metadata, and (b) mechanisms to deliver the actual data to dissemination-aware receivers. We studied how reliability guarantees/performance tradeoffs can be achieved by a careful instantiation of these two components. We installed RADcast on mobile devices inside a middleware and determined its feasibility. RADcast was also simulated, and our analysis indicated RADcast reaches an extremely high performance in terms of delivery ratio and latency, especially in light-weight networks.

In our current work, we are exploring a unicast-based approach for reliable broadcasting in MANETs. While broadcast based techniques generate lower latency per message transmission than unicast approaches (that need to sense channel availabilities), the broadcast mechanism is inherently unreliable with no interference avoidance ability. In highly congested networks, this can cause a high ratio of packet loss due to collision; a similar condition occurs when message sizes are large. This significantly decreases delivery ratios and in turn lowers the overall latency of data dissemination. Currently, we are investigating unicast based dissemination techniques for MANETs that aims to achieve high reliability, and low latency. In this approach, nodes are grouped into clusters and metadata is communicated via unicast throughout the network. Using the received metadata, nodes exchange missing portions of data efficiently by exploiting the inherent overhearing capabilities of nodes.

Notifications over Instant Mesh Networks: Our current and future work aims at exploiting multiple heterogeneous networks simultaneously for information dissemination. Given their ease of deployment, wireless mesh networks are increasingly being considered as feasible technologies that can be used to create temporary network infrastructures in situations where regular infrastructures are spotty, disrupted or non-existent. We explore techniques to effectively create and use ***"instant mesh networks",*** i.e., wireless mesh networks that are dynamically deployed in temporary circumstances – in addition to enabling coverage for internal onsite communications, such a network will support information flow into and out of the deployment site through gateway routers (mesh routers that connect to an external backhaul). In mission critical environments, off-site personnel create site maps (often accessing external GIS databases) and annotate them with commands that must be instantaneously disseminated to on-site recipients carrying mobile devices. Additionally, on-site responders carrying on-board sensors may communicate streams of multi-modal information (images, speech, other sensor data) to the off-site specialists who can further analyze the information to create better situational awareness of the scene. Our experience in using commercial mesh routers to create instant mesh networks in emergency response scenarios[DMP10] has exposed issues that are often faced in creating such instant mesh networks. Typical constraints that one faces in creating such instant networks are (1) need for quick deployment in uncooperative environments (2) cost and feasibility of gateway deployment – how many gateways to deploy and where to place them (3)enabling timeliness and reliability of communication relies on effective network configuration.

Figure 1: An Instant Mesh Overlay Network



Our approach is to establish a tactical instant mesh overlay network where mesh routers are placed such that they form a connected network that covers the entire region of interest; one or more mesh nodes serve as gateways that connect to a network backhaul. Mobile nodes in the region of interest send and receive information from/to the external world and other mobile nodes through gateways (i.e. mesh routers) and via ad-hoc communication amongst themselves. Our experience indicates that designating the proper gateway(s) significantly affects performance of communication in the networks described above, specifically in terms of latency and deployment time. The latency in this case, is calculated as the sum of the backbone latency (the time it takes data to flow between the gateway and the mesh routers) and the client latency (the time data is transmitted between the router and the mobile node associated with it). Our first target domain is one in which the communication does not place a heavy load on the network. In such network conditions, the client latency is easily determined, however the backbone latency is heavily dependent on the location of the gateway in the network topology and is much more complex to determine. An ideal gateway that would lead to minimum latency forms a shortest path spanning tree over the mesh network. We explore the intuition that a gateway at center of the topology would incur shorter backbone latency than the one at the perimeter[XDMV10]. We model the problem as determining a vertex with maximum centrality in a graph, and develop an approximation approach to locate such a vertex quickly and efficiently.

Concluding Remarks: We are currently working to expand our work in several directions. Our initial work assumes that the content to be disseminated in the instant mesh network is not voluminous – dealing with large size and streaming data might place different constraint s on the gateway selection process. In fact, it is not straightforward to determine how many routers should be used and how they should be placed to fully cover a specific area – factors such as area size, terrains, and the density of interference sources in the area become relevant and network distance is no longer the only factor determining network latency. Techniques to determine how and when to exploit direct ad hoc links between mobile nodes that then communicate with mesh routers based to generate low latency data flow between mobile nodes and mesh routers are also topics of current and future work. Eventually, our goal is to design frameworks that can to compose and adapt the above suite of protocols to enable rapid and robust communications as connectivities and communication needs vary.

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