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Mobile Wireless Active Networking: Issues and Research Agenda

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Abstract

Active network research has made significant strides over the last several years. While current research focuses on using active networking technology in wired networks, with emphasis gradually moving from active language environments toward dynamic service deployment, highly mobile and ad hoc networks open a completely new and challenging area of applications. We argue that active network technology will be most instrumental in situations with a relatively high ratio of the availability of processing and memory to bandwidth, which applies to many mobile computing situations. Furthermore, ad hoc nodes already have the characteristic of being both end and intermediate system, and thus share many of the resource and security issues with active nodes in general. There is large range of algorithms and protocols to which active technology can be applied (and benefit from), including autoconfiguration, self-organisation, resource discovery, novel application and content-oriented routing, simultaneous protocol and addressing mode support, dynamic service deployment, and session control using secure overlays. Unlike the traditional Internet, ad hoc and sensor networks do not have significant agreement on protocol standards, and thus there is a unique opportunity for active networking to actually facilitate the deployment of mobile wireless networks by providing a systematic and flexible protocol framework, without requiring over-standardisation of individual protocols.

1 Introduction

Mobile wireless networks are ripe for the application of active networking technology. The dynamic behaviour of mobile nodes and the inherently complex and time varying characteristics of wireless channels provide significant additional motivation for intelligence in network nodes over wireless networks. Indeed, much of the research in the MANET (mobile ad hoc network) community is struggling with how to do this; active networking provides a systematic framework that requires less a priori agreement on algorithms and mechanisms leading to standards. There may be real opportunity here to provide the infrastructure that *enables* ad hoc networking and its interworking with the traditional Internet before standards are codified.

There are a number of common assumptions about the Internet that are likely to be invalid in the future; some of these have particular importance in the mobile wireless networking environment.

1. Any meaningful distinction between wireless and wired networks will disappear. This substantially increases the heterogeneity of the network, and indicates that not only is mobile wireless networking a valid pursuit in its own right, but that its understanding is valid for the Internet as a whole. The vastly different characteristics of mobile wireless links from (for example) optical core links present opportunity for intelligent adaptation at the boundaries.
2. The distinction between an end system and a switch will disappear; this is the nature of mobile ad hoc networks. This is a natural match for active network nodes, which also have both end and intermediate system aspects, with the resulting resource protection and security implications.
3. Increasingly, nodes may not have IP addresses for a variety of reasons, including the complexity of address administration (or autoconfiguration), other natural means for node identification such as geolocation, the desire of nodes to be anonymous, or huge quantities of identical amorphous nodes. The canonical example of addressless nodes are sensors. Furthermore, there is doubt that IP addressing limits will ever get fixed by IPv6 deployment. As we move toward multiple end systems per user (tens at least, and perhaps hundreds or thousands) we must plan for tera- and peta-node networks. Thus, there is a need for a fuzzier waist of the Internet hourglass in which multiple addressing and forwarding modes are simultaneously supported, in addition to IP.

2 Different Tradeoffs

Active processing is enabled by the decreasing cost of processing and memory, but it is actually the *ratio* of the availability of processing *P* and memory *M* to bandwidth *B* that is important for a large class of active applications [1]. In particular, it is this ratio that determines how much active processing can occur per flow or transaction. While processing and memory are more abundant, so is bandwidth in the wired network. High-speed links (e.g. DWDM OC-192 or OC-768) have an inherently low $P{+}M/B$ ratio.

Wireless links have significantly more modest bandwidth capacity, however. To the degree that it is channel limited, there is opportunity for significant active processing. To the degree that the node itself is power limited, a more delicate balance exists between processing and communication transmission/reception. This is particularly the case for sensor (sub)networks and sensors that are part of a personal area network.

Note however, that active processing may help improve transmission and reception efficiency, by controlling transmission power and limiting the time that transmitters and receivers are powered. A final consideration in this area is that the same limited bandwidth in wireless networks also limits the ability for mobile code as a mechanism to transport active code. While occasional protocol and active code provisioning is likely to be feasible (exploiting the broadcast medium), highly dynamic code provisioning must be traded against application goodput.

3 Node Specialisation

One of the fundamental differences between an active node and a conventional router or switch is that an active node has characteristics of both an end system and intermediate system. The active node reference architecture and security architecture recognises the need to control resources so that active applications do not interfere with one another and the normal forwarding service of the node. Commercial implementations of active nodes will need to have all of the filtering and classification functions in the hardware fast path of each interface, and per flow and datapath active processing located with each link interface.

Mobile wireless ad hoc nodes inherently serve both as end systems and as intermediate systems that pass transit traffic to allow the construction of a multihop network. Thus, many of the resource and security issues are common to both ad hoc (passive) networks and active networks. Generalising the active networking solutions to the needs of ad hoc networks is critical. There are a number of characteristics of mobile wireless networks that make these problems even more difficult so solve, such as limited bandwidth, unreliability of links, and the likelihood that infrastructure facilities such as certificate and key servers may be inaccessible.

4 Mobile Wireless Node Architecture

We can think about someof the implications on the active node reference architecture. In the current model, all activity occurs at or above the network layer. In a mobile wireless active network, additional control is needed. On the receive interface, physical layer coding may have to be dynamically sensed, and channel conditions monitored to provide input for active processing. Active code may schedule and control when the receiver is powered on and able to receive. Frames may be filtered for active processing based on link and MAC layer headers. In the control plane, link and MAC protocols and parameters may be dynamically changed, or simultaneously supported. On the transmit side, active processing may control link and MAC layer framing, transmission parameters and power-on activity, and physical layer coding.

Note that this processing on the interface drives toward a distributed architecture in which active applications operate on the interfaces, rather than in central processor of the node. This is a requirement for any high performance node with multiple interfaces, which already distribute classification, address lookup, and output scheduling in interface modules.

Sensor networks and computational fabrics (e.g. electronic textiles) present particular challenges and opportunities. The challenges come from the extreme simplicity required in the node resources (processing, memory, and energy consumption). The opportunities come in the ability to use active code to achieve an overall reduction in these resources, and to embed evolving code into sensors to dynamically adapt to changing channel conditions and application requirements.

5 Opportunities for Active Protocols

There are a large number of opportunities for active processing in mobile wireless networks. Note that there is a fine line between calling some this "active" versus an algorithm built in the node. Doing it as active processing allows dynamic provision without codification of standards and preconfiguration, as well as natural coexistence of multiple algorithms. Some of these protocols and algorithms include:

- Address or identifier assignment, in the case of nodes that need them and are not preconfigured; note that amorphous and anonymous nodes will not have identifiers at all
- Neighbour discovery and link formation into layer 2 connectivity structures, with power control for degree of connectivity and protection against network partition, perhaps constrained by policy and node characteristics
- Self organisation and federation into layer 3 connectivity structures, with hierarchical clusters for scalability, perhaps constrained by policy and node characteristics; low level network service discovery may be necessary (e.g. name resolution, security)
- Topology optimisation and maintenance of cluster membership and link formation over time as nodes move and channel characteristics change; note that there is a difficult tradeoff between address reassignment versus translation for mobile nodes in a clustered hierarchy
- Resource discovery for sessions and applications, including servers, gateways, and transcoders
- Rapid automatic service creation, deployment, and composition in the presence of dynamically changing and intermittently available service infrastructure
- Session control of a set of transport layer associations, which must support highly dynamic multipoint behaviour with leave/join and merge/split; this may require the provision of a secure overlay on the clustered hierarchy.

All of these protocols can benefit from context-awareness. For example, many mobile services can exploit geolocation dependence, and high-velocity mobile nodes can use trajectory information to optimize routing topology and cluster federation updates. Similarly, the ability to sense administrative location can assist in the optimisation of the relationship of layer 3 cluster topology to a secure overlay structure.

6 Multimodal Protocols and Lower Layers

Active networking allows the support of arbitrary protocol processing. At the network layer, this can range from custom protocol processing (e.g. multicast, congestion control), through simultaneous protocol version support (e.g. IPv4 and IPv6), to support for completely distinct network layers and forwarding modes (e.g. IP forwarding, characteristics-based, and geolocation such as Cartesian or diffusion; see [2] for more on this). Conventional wired networks have relatively fixed topologies and link technologies, however.

Wireless networks provide the opportunity to move active processing down through the MAC, link, and physical layers. Active processing can be used to dynamically adapt parameters for MAC (e.g. TDMA slot length and CDMA codes), link (e.g. FEC strength and frame length), and physical transceivers (e.g. channel coding and transmission power). At the extreme end of the spectrum, the entire protocol suite can be adapted to the dynamic nature of mobile nodes and changing channelcharacteristics. For example, nodes may dynamically negotiate with one another to select the appropriate MAC protocol (e.g. TDMA vs. CDMA) and spectrum use to adapt to mobility, fading channels, andtraffic conditions. Software radios and programmable hardware naturally enable this technology. Optimisations such as ILP (integrated layer processing) can extend all the way down to the physical layer when appropriate, in an arbitrary mix of embedded controller software and programmable hardware.

7 Magnetic Routing

Magnetic routing is a paradigm in which messages and information are routed based on a field that governs the attraction of packets toward a destination. We have considered two flavors of this:

1. **Information pull** is a mode in which a mobile node pulls information behind it; in this case the force is of an elastic nature similar to a spring. As a node moves further from a node containing information (e.g. content cache), the cost function increases to the point that the information migrates (through a high bandwidth wired network when available) to be closer to the node. The optimisation here is the latency of information access and channel bandwidth traded against the cost of data migration.
2. **Information seek** is a mode in which messages wander through the network looking for a particular type of information. When a force field with sufficient strength and characteristics are encountered, the message is attracted to the appropriate node.

8 Rapid Service Deployment

Service creation and deployment is challenging enough in the context of wired networks; it is a significantly harder problem in mobile wireless networks due to:

- the inavailability of reliable fixed infrastructure, requiring minimal reliance on such resources with distributed peer-to-peer service creation when possible
- the need for rapid autoconfiguration of basic network layer services to enable mobile nodes to initially use the network
- the need for services to dynamically adapt to mobility and time-varying channel conditions, to degrade gracefully as some resources disappear, and to automatically reconstitute as resources reappear

Mobile nodes can adapt to these conditions by preparing to assume some of these service infrastructure roles while the primary resources are unavailable. For example, nodes can cache name resolutions and address bindings to temporarily perform binding and routing when these servers are unavailable. Inter-node active processing can allow nodes to assume these functions for one another without requiring all of them to contain the processing and memory to perform all of them. Clearly, this load balancing should also be power aware.

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