Structure Routing for Mobile Appliances

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Abstract

In this paper, we consider the problem of providing multi-hop wireless access to mobile appliances. We propose to use structural information inherent in a mobile application environment to assist routing. Via three application scenarios, we show that network addresses can conveniently encode structural information such as organization hierarchy, network access services, and quality of network access. By only examining such encoded addresses of its neighbors, a mobile device can make intelligent packet forwarding decisions, without relying on general routing protocols. Structure-based routing greatly simplifies routing and network management, enables highly scalable mobile networks, supports open access by allowing horizontal service providers, and minimizes network support requirements for mobile appliances. Using the approach, ultra-thin personal appliances, such as wristwatch-based server devices, can easily connect to the network.

1. Introduction

1.1. The Mobile Appliance Access Problem

Internet appliances equipped with low-cost and short-range radios such as Bluetooth [1] and HomeRF [7] are expected to be widespread. Using Mobile IP [19] such appliances can be servers capable of receiving connection requests. Remote users can thus control or push data to these appliances from anywhere. Many of these appliances can be extremely useful and convenient in daily life.

However, providing the required infrastructures for achieving this vision has been a challenge. For example, to support network connection for a mobile appliance equipped with a short-range radio, gateways will need to be deployed in near vicinity. In addition, a gateway itself may need to use other wireless links to reach a wired network. Providing connection to a mobile device may therefore involve multiple wireless hops and travel through several administrative domains.

1.2. Proposed Solution

We present “structure routing” as a means for providing simple network access for mobile appliances. Structure
Routing is a concept that takes advantage of the inherent structure present in an application. For example, in some applications such as the battlefield scenario of Section 3, communications are primarily hierarchical, not peer-to-peer, and this hierarchical structure can greatly simplify routing. The approach utilizes the network addressing mechanism that any network connected mobile appliance and its environment must equip anyway, to encode the structure itself. This is in contrast to traditional routing that assumes no special structure in the application—it is up to the routing protocol to establish the network structure.

Lightweight directory services [25] may provide similar functionality in terms of obtaining network access and routing information. However, why assume additional infrastructure in the network? We are interested in a minimalist approach for connectivity bootstrap. A mobile device already has an address—exploit it for all necessary network services: network access, routing, and selecting network service levels. Without dependence on infrastructure such as directory services, mobile appliances can rely on minimal network support, and they can be manufactured and deployed without making too many assumptions about networking.

1.3. A Preview of the Paper

In Section 2, we describe related work in the literature.

In Sections 3, 4 and 5, we discuss three application scenarios that correspond to situations with devices under a single administrative domain, multiple administrative domains, and dynamic domains. Devices in a single administrative domain can achieve simple and robust routing using organizational hierarchy which may be inherent in an application. For multiple administrative domains, ease of deployment and management can be realized using "service IP addresses" that indicate service membership in a collection of mobile devices. Simple appliances desiring network access may have a choice of attachment points. “Service level encodings” provide these dynamic domains with simple network access decisions by the mobile appliances that satisfy their own unique access requirements.

In Section 6, we conclude that structure routing can indeed take advantage of the structure in various application scenarios to aid minimalist mobile devices in gaining network access. We argue that structure routing is a powerful mechanism to simplify network access and routing for thin mobile appliances.

2. Related Work

Routing in stationary networks is a well-researched topic. Typically, routing algorithms are global—all nodes in the network participate in signaling and maintain some state. Addressing may be hierarchical, as in landmark hierarchies [24], or open, as in a proposed Internet routing algorithm [16] and the Internet [9,13,15,21].

In the first case, hierarchical addresses permit less routing message exchange. If the topology changes, addresses must be reassigned. This is done through global hierarchy management algorithms. In the open addressing cases, node addresses are static, but the nodes must exchange more routing updates. We use static node addresses in addition to having small management overhead without a global routing protocol.

Mobile ad-hoc networks consist of mobile nodes communicating over wireless channels. Several protocols have been designed for these conditions [2]. Those protocols are general—they do not exploit existing structure inherent to a specific application or administrative configuration. Under high mobility, ad-hoc protocols typically perform expensive management of routing information, in terms of the amount of overhead traffic [3]. In the three application scenarios, we show how to use structure to minimize routing overheads.

The IETF Mobile IP working group has addressed mobility of nodes in the IP network. The group has produced a set of specifications [19] which define a standard way of steering traffic to roaming hosts’ current locations. The Mobile IP approach provides a solution for roaming nodes attached directly to the wired network via a single wireless hop. In contrast, we address in this paper the problem of providing access across multiple wireless hops for mobile appliances.

As depicted in Figure 1 and mentioned earlier, the Mobile IP’s roaming solution over the wired Internet and this paper’s structure-based routing solution over a wireless region can work together. This will allow mobile appliances to be reachable from anywhere. Thus the approach of this paper will help extend the utility of Mobile IP in the area of mobile appliances. We will elaborate this point in the following three sections where various application scenarios are discussed.

Lightweight directory services assume a directory infrastructure which is explicitly queried for various information, such as location data [12], local service discovery [8], router discovery [4], dynamic configuration [5], etc. Such methods rely on additional protocol infrastructure for the wireless network and for the appliance that the minimalist approach taken by this paper does not want to assume. The solution of this paper provides a minimum bootstrap method to connect appliances to the network. After connection establishment, appliances can use any directory services available on the network.
3. Application 1: Use of Hierarchical Structure in a Single Administrative Domain

This section considers an application of structure-based routing in a mobile environment which is under a single administrative domain.

3.1. Battlefield Application Scenario

Let us imagine a digital battlefield [22] where commanders and soldiers carry wireless communication devices and data terminals so that they can send and receive commands between the rank hierarchies. In order to maximize utility and bandwidth of the radio spectrum, the military units may carry wireless devices of mixed characteristics in terms of different radio ranges and protocols. In particular, soldiers carry short-range devices to facilitate their mobility while commanders carry long-range devices to control soldiers scattered nearby. Mobile vehicular units with base stations roam about with spotty local coverage to provide uplinks to the central command.

Traffic patterns are mostly hierarchical, for example, between soldiers and their commander. Direct peer-to-peer communications are not essential.

The hosts within the network reside in a single administrative domain. The single administration allows a high degree of flexibility in network configuration. For example, private network addresses can be configured for mobile devices to facilitate a routing scheme.

For a networking solution to this application, robustness and simplicity are the primary objectives. Robustness is essential because of the uncertain environment where nodes in the hierarchy may become unavailable at any given moment in time, not only because of mobility but also because of equipment failure in the field. Simplicity in required routing support is crucial because the mobile devices themselves are simple.

We will present a routing system that takes advantage of the command hierarchy structure inherent to the application.

3.2. Hierarchical Structure in Battlefield Application Scenario

Consider a tree of communicating parties in the application, based on their rank, radio communications capacity, and mobility requirements. For example, privates are child nodes of their sergeants; sergeants are child nodes of their captains; and so on. An interesting characteristic of this structure is that when a node moves, it moves along with the subtree to which it belongs—a private usually moves close with his sergeant or captain, together with the other privates belonging to that squadron. A squad moves with the company along with the other squads.

The command hierarchy also applies to network traffic. As noted earlier, the soldiers communicate with their immediate parent node. Peer-to-peer communication is not as vital. Child nodes cannot and should not communicate amongst each other directly. Besides the reason of maintaining the chain of command, this may also be for the reason that they may not be within radio range of each other at all times and their devices are too simple to carry complex routing code at the peer level. The parent node can have short-range radio equipment that covers the geographical area of the soldiers’ positions. In addition, it can have a long-range radio up-link to its immediate parent node.

3.3. Structured Routing for Battlefield Application Scenario

Our routing algorithm will take advantage of this structure inherent in the application. Every node is configured with a default parent node that forwards all inbound and outbound packets for the node. When its parent is not reachable, the node will find another node to be its new default router. It will find the most immediate ancestor that is reachable in the hierarchy. For example, privates should contact their sergeant’s captain instead of the command center directly, when possible.

To enable router discovery, we use hierarchical subnet addressing, whose configuration should be feasible under our assumption of a single administration domain. Nodes providing forwarding service will send out periodic beacons containing address advertisements. At each level of the hierarchy, the router nodes will advertise their addresses and subnet masks whose lengths increase down the hierarchy.

We illustrate the addressing structure with Figure 2. For the branch leading to private A, the military command center has an address of 1.X.X.X with mask length of 1 byte; the captain has an address of 1.1.X.X with mask length of 2 bytes; the commanding sergeant has an address of 1.1.1.X with mask length of 3 bytes; and the private has an address of 1.1.1.1 with mask length of 4 bytes. Outbound traffic follows matching nodes with decreasing mask length; inbound traffic is the opposite. This is similar to landmark hierarchies [24], except that we utilize the external command hierarchy to form proper network configuration. Our node addressing structure is static, and does not change when network topology changes. It is also similar to hierarchical state routing [18] with the difference of performing router discovery instead of restructuring addresses when the routing topology changes.

A child node will select a new parent node upon timeout of beacon receipts from a prior parent. The selection mechanism is simple and greedy: a node will select the
router with maximal prefix matches, or in other words, the nearest ancestor that is reachable in the tree.

In the addressing structure above, when the sergeant is not available and if the private is in radio range of both the captain and the command center, the soldier will select the captain (its address of 1.1 matches 1.1.2.1 with maximal prefix length compared to the other ancestors) as the default router. To avoid routing loops, the node will avoid selecting any node whose subnet mask is equal or longer than its own.

This communication network can be implemented with off-the-shelf devices and standard Internet protocols. For the wireless device, the network only requires point-to-point communication; broadcast can be generalized on top of point-to-point links. Broadcast, however, facilitates efficient implementation of beacons. 802.11 wireless Ethernet and Bluetooth are possible device candidates. For the network protocol, we can use IP. The exact delivery protocol is not essential—routing here only utilizes hierarchical subnetting to infer the network configuration.

To implement the router selection correctly, a node must be able to retrieve information about the potential routers that it can attach to prior to attachment. This can be done either by listening to broadcast beacons, scanning all the frequency spectrums and listening for beacons, or by using a network identification field like with 802.11 Ethernet to differentiate between networks. Once the routers’ addresses and subnet masks are retrieved, the node can determine which router to attach to.

### 3.4. Advantages

The structure-based routing approach described above is advantageous in terms of providing simple and robust connectivity for the mobile nodes. Not having to exchange routing information using routing protocols such as RIP and OSPF reduces the management and configuration complexity of providing robust connectivity in uncertain environments. In addition, it avoids the volume of update traffic and slow convergence on a large network.

The addresses of nodes can embody the organizational structure to quickly adapt to changing situations. For example, as commented earlier when a mobile node cannot find its parent node within range, if it is in range of some ancestor nodes, it will reconnect to the network itself via one of them without additional information such as route updates from others.

The strategy of using organizational hierarchy to assist routing over wireless networks can apply to other applications. Emergency rescue teams, which exhibit similar hierarchical command structures with a single administration authority, represent such an example.

### 4. Application 2: Use of Access Service Structure in Multiple Administrative Domains

This section considers an application of structure-based routing in a mobile environment involving multiple administrative domains.

#### 4.1. Bus Application Scenario

Consider the scenario where a passenger on a bus needs to receive pushed information such as stock quotes on his watch-based server periodically. As depicted by Figure 3, the network connection is achieved via three wireless links: (1) a short-range radio such as Bluetooth connecting his watch to his or her laptop; (2) a medium-range radio such as WaveLAN [11] connecting his or her laptop to an access point on the bus; and (3) a metropolitan scale radio such as Metricom [14] connecting the access point on the bus to base stations in various bus terminals.

The general problem illustrated by this bus application scenario is that of making ultra-thin mobile appliances, such as the passenger’s watch, reachable from the wide-area network. We wish to solve this in an open and scalable manner.
Existing monolithic service providers of wide area wireless access fail to leverage the advantages of simple thin appliances. Single-hop networks such as the cellular networks have problems with achieving the bandwidth that appliances desire beyond simple voice communication. Companies like Metricom which operate a multi-hop wireless data network [23] can provide relatively high bandwidths. However, partly because the entire network is under a single operating domain, their adoption has so far been quite limited.

4.2. Access Service Structure in Bus Application Scenario

We suggest that a key to widespread networking support of thin mobile appliances will be an open access structure between multiple management domains, similar to that for the wired Internet. Multiple service providers coexist at all levels of the access hierarchy.

These appliances require simple access to the wide-area network instead of communicating within the wireless network. For ubiquity, the appliances may sport the same type of wireless radio hardware. Service providers offer network access for these appliances. Service providers themselves may require access to the wider network for their access point devices.

In order to make simple appliances with the desired application bandwidth, their radio range cannot extend too far. Thus, for the end-appliances, service providers may only provide wireless access service for a limited number of areas using very short-range radios. They may rely on the upper layers of the access hierarchy that other service providers (carriers) manage, to complete the connectivity for the end user. Because of the limited radio range, users may realistically connect to one access point at a time. In addition to different providers at different layers of the hierarchy, multiple service providers may offer access service at the same layer in the hierarchy. Providers may coexist to manage different users with the same wireless equipment.

We believe that because of rapid advances, radio technology is not likely to be an obstacle in realizing this open access vision. A major challenge, however, will be in management, especially, in handling issues related to multiple heterogeneous service domains.

4.3. Structure Routing for Bus Application Scenario

With the knowledge of this hierarchical service network outlined above, we can apply the structure routing principle to simplify management. We present a mechanism for interconnecting these different domains of network access to ease management and configuration at the mobile appliances.

We introduce the notion of service IP addresses, which appliances may use to bind to a particular domain’s network access point. Similar to the default-gateway address, the specific service IP address binds the appliance to the access point servicing the end-user layer. The service IP address allows simple appliances to reach access points without any sort of router discovery among the coexisting service providers.

As with the previous scenario of Section 3, we suggest that link layer hardware do not make gateway or base station selection until the IP or network layer access is correctly resolved by recognition of the service IP address. The mobile host may examine the service IP addresses in beacons from the gateways to decide on a binding. This allows for flexible hardware that opens the access architecture for management by multiple coexisting providers.

Similar to how appliances bind to a particular service provider’s domain, a service provider’s access point may bind to a particular carrier’s gateway. In other words, service IP addresses delineate the tiers of service providers.
4.4. Illustration of Service IP Routing for the Bus Application

Consider the use of service IP addresses in the bus application scenario of Figure 3. The manufacturer of the watch may decide to hard-code the IP address and the manufacturer’s home agent address onto the device. Thus the watch can always be reached at this permanent IP address via protocols such as Mobile IP.

The watch may also be hardwired with a fixed IP address to identify its default gateway. The passenger’s laptop, which the watch will use as its immediate gateway, is configured to act as the default gateway for the watch. For this, the laptop may just need to run some configuration installation program supplied by the watch manufacturer.

To secure a connection to the access point on the bus, the passenger will set his or her laptop’s default gateway to be the service IP address published by the bus operating company. The passenger maintains constant access as long as he or she remains on the same company’s bus line. The bus itself establishes external network connectivity through bus terminals whose service IP address is well known. The bus may travel between terminals in different regions but it will maintain connectivity regardless of its location, provided that the terminals use the same service IP address. (See Section 4.5 for an implementation demonstrating this concept of using a fixed service IP address for a mobile node to gain network access.)

We illustrate these points using Figure 4. A passenger with his or her laptop configured to use company X’s service IP address as its default gateway will remain connected when moving from bus (1) to bus (2).

After bus (2) switches its external gateway from terminal (a) to (c), it will remain connected, provided that the two corresponding terminal authorities support the same service IP address that the bus uses for its external connection to the terminals.

4.5. Implementation of Service IP Routing

We have completed an implementation of a service IP routing scenario running on two types of wireless links. In this scenario, the thin mobile appliance was a NEC MobilePro 800 handheld PC running Windows CE, equipped with a Metricom Ricochet wireless modem. The gateway serving this device used similar hardware, but ran NetBSD [17]. In addition to the downstream Metricom interface, a Lucent 802.11 WaveLAN card connected the gateway in the upstream direction. The top level gateways bridged access between the wired campus network and the Lucent 802.11 WaveLAN access points that connected with the mobile gateways. Fixed service IP addresses were assigned to the wireless interfaces on the gateways of both layers, as illustrated in Figure 5:

Service IP 1  Service IP 2

FreeBSD  NetBSD  WinCE

IEEE 802.11  Metricom

Layer 1  Layer 2

Campus Network

Figure 5. Our implementation of a two-layer Service IP Routing scenario. The Layer 2 device gains access through the Layer 1 gateway, which in turn connects through the wired router.

The service IP routing approach allowed straightforward implementation of the “mobile appliance”. The device ran on Windows CE as-is with a fixed default gateway address (the service IP address of the mobile gateway) and a small user-level registration daemon.

Using this implementation, we can show that a mobile Windows CE device, with its default gateway configured to be the service IP address of its access layer, can maintain network connections while it roams between different radio regions, as long as they use the same service IP address.
4.6. Advantages

The service IP routing illustrated above has a number of advantages. Configuration and management for the users are simple. Beyond selecting a default gateway among the few service IP addresses, the mobile host need not worry about routing and access details. Manufacturers can even support a hard-coded set of addresses for users to choose when there are pre-existing agreements between service providers.

Thin appliances such as watches do not need complex router discovery logic or routing logic to gain access through the bus and terminal access providers. If the user wishes to connect to different service providers at different points in time, then he or she may change the service IP address accordingly.

This hierarchical service architecture allows thin appliances to enjoy broadband transmission. For example, a wristwatch-based server can use a short-range, yet high-bandwidth radio to connect to a nearby access point provided by an intermediary service provider. The access point can connect to the external world via another service provider in the access layer above, using a more powerful and higher bandwidth radio than the one used by the wrist-watch.

The service hierarchy is highly scalable. At each level, single or multiple administration domains may provide mobile access service to the domains below. Any mobile appliance may gain access to the wide area network through the hierarchy. The upper layers of the access hierarchy may provide routing and forwarding service for the end appliances in a simple fashion using layered Mobile IP, source routing [20] or Network Address Translation [6].

5. Application 3: Use of Access Resource Structure in a Dynamic Domain

We discuss an application of structure-based routing in a mobile telephony environment with dynamic access domains.

5.1. Access Resource Requirements for Mobile Appliances

Suppose a mobile user has a few wireless gadgets on his or her person: a wireless watch that dubs as a simple mobile phone and a wireless shoe that acts as a wireless router for other devices on the person. Other users, wishing to call the mobile user, connect to the watch’s static IP address, like dialing a phone number. The user’s car is equipped with radio interfaces that provide gateway services. The user’s environment such as the office room or outdoor access points provides network access services. How can the wireless watch select the best access point at all times? The watch should access the network in a manner that is best for its telephony application.

Traditional mobile IP or ad-hoc routing algorithms do not provide the level of routing choice that may be desired for lightweight use. Lightweight devices may need to choose among many potential default gateways. Each device may have different criteria for network access, depending on the circumstances of the application. For example, a stock-ticker appliance may require minimal latency and high reliability; on the other hand, a wireless streaming radio may require maximal bandwidth, but it can disregard latency. We present a minimal scheme for choosing resources that require no more than the existing addressing infrastructure, using the inherent network access structure that is present for thin mobile devices.

5.2. Access Resource Structure for Dynamic Domains

The access structure for the watch requires dynamic binding to the most appropriate gateway from the application’s point of view. The watch must quickly evaluate its options for network access without sacrificing its thin and simple logic. The limited radio range of the watch suggests that a hierarchy of mobile access is a necessary solution. However, unlike in Application 2 of Section 4, the watch is not bound to membership in a particular service domain—rather, its application requirements dictate its choice of a default gateway.

In order to support lightweight network access, we make use of “service level encoding”. The wireless hosts can view the default gateway’s IP address, not as a mapping to the gateway itself but an encoding of the gateway’s network service description. For instance, a wireless gateway can advertise its services to other wireless mobile hosts with an encoding that describes its network up-link according to a matrix: a 4-tuple (bandwidth, latency, reliability, radio range), for example.

It is up to the client mobile host to select a default gateway depending on the device’s criteria. The mobile hosts can perform simple selection among the gateways, such as maximizing the access bandwidth or minimizing latency. Wireless clients must only listen for advertisements by different routers. They need not perform explicit solicitation. This is more general than special tags such as preference level fields in ICMP router discovery [4].

5.3. Structure Access for an IP Telephony Application

We give an example of the utility of access resource encodings or service level encodings. We assume that
mobile appliances have 1) radio devices that can broadcast onto a common channel and 2) have a MAC-IP address mapping similar to Ethernet ARP. We also assume that mobile IP is used to interface the wireless and wired border.

The watch obtains network connectivity by finding an appropriate gateway. It has a simple short-range radio like Bluetooth [1] or Home RF [7]. At any given point in time, there may be a multitude of potential gateways that may or may not be wireless hosts themselves. The watch selects a gateway in the immediate environment depending on some simple criterion: it tries to maximize bandwidth, minimize latency, and maximize link reliability. The watch prefers to connect to a wired gateway if possible.

The wireless shoe has mechanisms for generating power [10] and room for larger battery capacity such that it can power a radio device with longer range as well as having a short range Bluetooth interface. It provides forwarding services for other wireless devices on the person that have limited radio range. It can act as a gateway for the watch, advertising its IP address with an encoding of (low bandwidth, high latency, high reliability, medium radio range). The watch would only use the shoe as a gateway in the event that it cannot obtain radio connectivity through an alternate gateway with better network access.

The user’s car is equipped with Bluetooth and a radio device that has very long range. It advertises itself as a gateway with service level encoding of (low bandwidth, high latency, low reliability, long radio range).

The user’s work environment has access points scattered throughout. The user’s office room provides gateway services through a laptop computer that is both wired to the LAN and has Bluetooth. Its service level encoding would be (high bandwidth, low latency, high reliability, short range). The parking lot outside the user’s office building has minimal radio coverage linking back to the main building. Light poles provide medium range radio connectivity and advertise their encoding as (low bandwidth, medium latency, high reliability, medium range) in addition to sporting a short-range radio compatible with the shoe radio.

Suppose the user wishes to be reachable at all possible times through his or her watch at all possible locations. When the user is in the office room, possible gateways for the watch would be the shoe and the laptop computer. They both announce gateway advertisements to the watch over Bluetooth. Since the laptop computer’s advertised service level better satisfies the watch’s constraints, the watch will choose the laptop computer as its default gateway, as shown in Figure 6 (a). The watch need not know the laptop computer’s true address—MAC-IP mapping takes care of the address resolution.

Now suppose that the user leaves work and heads home. In the parking lot, the watch does not have adequate radio power to reach the routers in the light poles. However, the wireless shoe does, and it establishes connectivity through the light poles that advertise gateway services over their short-range radio, maintaining an up-link back to the office building over long-range radio. The wireless shoe then advertises itself as a gateway to the watch, who has just expired its gateway registration with the laptop computer. The watch now has connectivity back to the office through the light poles, as shown in Figure 6 (b).

When the user enters his or her car and drives away, the shoe roams out of range of the light poles. The shoe first expires its registration with the light pole. It then will regain connectivity through the car’s long-range radio, and it will proceed to advertise its updated service level address over Bluetooth. However, the watch will also hear the service level advertisements from the car itself. The watch, maximizing up-link bandwidth, will attach to the car instead of the shoe, as shown in Figure 6 (c).

5.4. Advantages

Service level addresses identify available resources of various access points. Using them, a mobile wireless host can select a gateway on demand depending on the application of interest. The mobile host can maximize or minimize any of the service characteristics as encoded in a gateway’s advertised service level. Since the mobile host has most knowledge about its own network access requirements, it is natural that the mobile device itself makes the final decision concerning default gateway binding. This network may support a diverse set of appliances in a generic fashion.

The use of service level encodings greatly simplifies network management and complexity at the mobile hosts. The mobile hosts can have very lightweight network stacks with simple routing or access protocols. The mobile hosts obtain a route to the wider area network via a specific up-link that matches the mobile application’s specific criterion. The gateway host simply needs to inform the potential mobile clients about its up-link characteristic in an encoded address. Why add more complexity than necessary when the

![Figure 6. Application 3: a watch in three scenarios with different access resources. In (a), the watch prefers the laptop’s faster uplink. In (b), the faster uplink (pole) is out of range, so access must be gained through an intermediary (shoe). In (c), a fast mobile uplink is available—the car's.](image-url)
address information in advertisement beacons can convey all the requirements?

6. Conclusion

In summary, structure routing assigns addresses to reflect the inherent structure in the application environment. By encoding organization hierarchy, network services, and quality of network access in the gateway addresses, structure routing can dramatically simplify mobile wireless networks. We have presented three scenarios that utilize this mechanism:

• In the first scenario, the gateway addresses directly reflect the organizational hierarchy. The physical hierarchy of the military guarantees that some gateway is always in range. Routing packets based on this structure avoids complex network management.

• In the second scenario, coexisting service providers can provision service IP addresses to segment the management domains. In this open environment, end users do not have to reconfigure their appliances to gain network access. Even very thin devices that do not have routing capabilities can roam freely in this network.

• In the third scenario, the addresses convey resource quality information for the mobile devices in the form of service level encoding. Mobile devices can opportunistically obtain the best network service they desire using simple local decisions. No complex routing is necessary—by examining only immediate neighbors, the devices can make fully qualified choices.

Sometimes an application may exhibit more than one type of structure. In this case, structure routing can make use of multiple structures simultaneously. For example, based on both their hierarchical and resource structures, a mobile node may select one of its neighboring nodes to be the next hop.

In general, using structure routing has a number of advantages:

• Service IP addresses promote an open network access architecture that supports service interoperability on common hardware without complex protocols. Multiple administrative domains may work together in providing high-bandwidth access for minimal end-appliances. The users need not manage the devices to maintain connectivity in foreign networks.

• Appliances can have a variety of network access options. Service level encoding encourages diverse access patterns over heterogeneous link types. The network can offer different qualities of service from which a mobile appliance can choose.

• Global routing is not essential for appliances, when a route to and from the egress gateway of the mobile environment is most important for connectivity. There is no need for complex routing protocols. Existing routing tables can be very small at the end devices.

• Routing information converges quickly without the need for global state synchronization. Unlike other ad-hoc routing algorithms that do flooding or other high-overhead information exchange, structure routing allows a node to locally select a gateway by listening to neighbors’ beacon messages.

• Structure routing makes network management for appliances easy. Without structure information, either complex routing protocols or some forms of directory services would have to be used.

• Structure routing allows easy implementations with commodity devices. Our implementation of multiprovider access service, described in Section 4.5, illustrates that a small system such as Windows CE can be used as an appliance without modification.

In conclusion, we have shown that structure routing provides simple and scalable access for mobile appliances. The framework allows for simplicity of the mobile appliances and ease of management. It represents a feasible approach to an open access infrastructure for mobile appliances.

References


