

Mobile Data Routing

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Field of the Invention

The present invention relates to the routing of data within communications
5 networks, including but not confined to networks such as the Internet, and
particularly, but not exclusively, to a method of routing data directed to a mobile
node. The mobile node may be a mobile host, such as a portable computer, or it
may be a router which is responsible for the mobility of one or more entire
networks, for example, the mobile data network within an aircraft. In either
10 case, the mobile node may change its point of attachment from one network or
subnetwork to another.

Background

The routing of data around the diverse networks which make up the Internet is
15 based on a protocol known as the Internet Protocol (IP). Data is transferred in
the form of data units known as IP datagrams between points in the Internet
specified by IP addresses. The use of IP hides the physical nature of the
underlying networks from application processes running over the Internet.
These networks may, for example, be a combination of wired and wireless local
20 and wide area networks using different physical protocols such as Ethernet and
token-ring, including networks linked by telephone through an Internet Service
Provider (ISP), or through satellite or ground based radio or infra-red links.

The detailed specification of IP is available in a "Request for Comments"
25 document, RFC 791, maintained by the Internet Engineering Task Force (IETF).
RFC documents are widely available on the Internet at, for example,
"ftp://ds.internic.net/rfc/rfcxxxx.txt", where "xxxx" represents the RFC
number, so that RFC 791 is available as rfc791.txt.

30 The current version of IP, known as IPv4, does not itself support mobility, but a
protocol entitled "IP Mobility Support", commonly referred to as Mobile IP, has

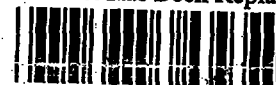
been designed to enhance IPv4 to support mobility. This protocol is described in document RFC 2002, available as detailed above. The next generation of IP (IPv6) is being specifically designed to deal with the mobility requirement.

5 IPv4 assumes that a node's IP address uniquely identifies the node's fixed point of attachment to the Internet. If the node is transferred to a different point, it can only be contacted by allocating it a new IP address. Mobile IP, however, enables a mobile node, such as a laptop or palmtop computer, to send and receive IP datagrams over the Internet regardless of the physical location at which it is
10 connected to the Internet and without changing its IP address. One example of the mechanism by which it does so is illustrated in Figures 1a and 1b.

Referring to Figure 1a, the Internet comprises a large number of networks and sub-networks 1, 2, 3, 4 connected via routers 5. A router may be a general
15 purpose computer programmed to perform routing tasks. Increasingly, routers throughout the Internet are dedicated pieces of hardware, controlled by software or firmware, provided by companies such as Cisco Systems, California, USA. In either case, the functionality of a router intended for use in an IP based network is defined in RFC 1812.

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A mobile node (MN) 6 is normally connected to the Internet via a home network 1. The unique IP address assigned to the node 6 is known as its home address. Mobility agents, known as foreign agents (FA) and home agents (HA), advertise their presence on a network via availability messages known as Agent
25 Advertisements. A mobility agent is typically a router connected to a particular network; for example, a home agent 7 is a router connected to the home network 1 and a foreign agent 8 is a router connected to a foreign network 2. The mobile node 6 may optionally solicit an Agent Advertisement message from any local mobility agents via an Agent Solicitation message. By receiving Agent
30 Advertisements, the mobile node 6 is able to determine whether it is on its home network 1 or on a foreign network 2, 3, 4.

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While the mobile node 6 is on its home network, it has no need for mobility services. When the mobile node 6 is temporarily moved to a foreign network 2, as shown by the dotted box in Figure 1a, it obtains a temporary care-of address
5 on the foreign network 2. This can be a foreign agent care-of address, which is the IP address of the foreign agent, obtained by receiving or soliciting Agent Advertisements from any foreign agents based on the foreign network 2. Alternatively, the care-of address may be obtained by using an external assignment mechanism, such as Dynamic Host Configuration Protocol (DHCP)
10 (the reader is referred to RFC 1541 for further information), in which case it is known as a co-located care-of address.

The mobile node 6 then registers its new care-of address with its home agent 7 by exchanging Registration Request and Registration Reply messages with it.
15 Registration provides a mechanism by which mobile nodes can communicate their current reachability information to their home agent. The registration process is described in more detail below, assuming that the mobile node 6 on the foreign network 2 is registering a foreign agent care-of address received via an Agent Advertisement from, for example, foreign agent 8.

20 First, the mobile node 6 sends a Registration Request message to the foreign agent 8, which processes it and forwards it to the mobile node's home agent 7. The Registration Request message includes the IP address of the foreign agent. The home agent 7 sends a Registration Reply message to the foreign agent 8
25 granting (or denying) the registration request. The foreign agent 8 processes this Reply and forwards it to the mobile node 6. This process establishes a temporary address for the mobile node 6 to which datagrams can be delivered while the node is roaming away from its home network 1.

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If the mobile node 6 is returning to its home network 1 having been on a foreign network 2, it deregisters with its home agent 7, through exchange of Registration Request and Registration Reply messages.

5 Referring to Figure 1b, when a correspondent node (CN) 9 attached to a network 4 sends a message intended for the mobile node 6, while it is connected to the foreign network 2, the message is intercepted by the home agent 7, as shown by arrow A. The home agent 7 encapsulates the datagrams forming the message with the care-of address for the mobile node 6, in this example being the
10 IP address of the foreign agent 8, and forwards the message to the foreign agent 8. The transmission of the encapsulated datagrams, shown by arrow B, is known as tunnelling. The foreign agent 8 receives the datagrams, decapsulates them and forwards them to the mobile node 6, as shown by arrow C. Messages from the mobile node 6 to other nodes in the Internet need not follow this route, but may
15 be sent directly via an appropriate router, which may be foreign agent 8.

The concepts of encapsulation and tunnelling are described in detail in RFC 2003, "IP Encapsulation within IP". The model is that a tunnel is the path followed by a datagram while encapsulated. Encapsulation allows an IP
20 datagram to be hidden from intermediate routers which would incorrectly attempt to route it to the mobile node. Instead, the datagram is routed between the encapsulator and a knowledgeable decapsulator, such as a foreign agent, which can correctly route the datagram. The home agent 7 and foreign agent 8 are known as the endpoints of the tunnel. In the case of the co-located care-of
25 address, the mobile node itself acts as an endpoint of the tunnel.

To enable the tunnelling process described above to function correctly, the home agent 7 maintains reachability information for the mobile node 6, in a form known as a mobility binding. This is the association of the mobile node's
30 identity with a care-of address and a parameter known as the Lifetime, which is the number of seconds remaining before the registration of the node 6 with the



home agent 7 expires. The aim behind a Lifetime value is to maintain the dynamic nature of the system, with a binding expiring within a set time unless positively maintained by the mobile node 6. As an example, the default Router Advertisement Lifetime value, which may be used where a mobile node is
5 registering with a foreign agent which it has acquired via an Agent Advertisement, is 1800 seconds.

On receipt of a Registration Request message, the home agent 7 creates or modifies the mobility binding, for example, by re-setting the Lifetime value
10 where the Request is a re-registration request and the mobility binding has not yet expired. If the Lifetime value for a given mobility binding expires before a re-registration request has been received, the home agent 7 deletes the mobility binding from its record. The Registration Reply message from the home agent 7 informs the mobile node 6 (via the foreign agent 8) of the status of its Request,
15 including the Lifetime value allocated by the home agent 7.

Mobile IP supports multiple simultaneous mobility bindings, so that each mobile node 6 may register with a number of foreign agents and so obtain a number of care-of addresses. This is particularly useful where a mobile node using a wireless
20 interface to a network, for example an RF interface, moves within range of more than one foreign agent. For example, if the mobile node is a router on an aircraft, then while the aircraft is in flight, the router may from time to time register with a series of foreign agents based on the ground below using a radio link.

25 In the case of multiple simultaneous mobility bindings, the home agent 7 retains its existing list of mobility bindings when it receives a Registration Request containing the IP address of a new foreign agent. If the Lifetime value of one mobility binding expires, the home agent 7 deletes that mobility binding from its
30 record, but retains in its record the other non-expired bindings.

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A problem with this method of data transmission arises when bandwidth bottlenecks occur in the forwarding of data from the home agent, either in the tunnelling routes or in the links between the foreign agents and the mobile node. For example, where the network links between the mobile node and the foreign agents are wireless links, these may have a substantially lower bandwidth than that available between the correspondent node and the home agent.

The primary role of the home agent and foreign agents is to provide the appropriate encapsulation and decapsulation to re-route data arriving at the mobile node's home network from a correspondent node, so as to reach the mobile node at its current location. The maximum data rate at which data can be received from the correspondent node without data loss is therefore limited to the data rate corresponding to the highest available bandwidth path between the home agent and mobile node.

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Summary of the Invention

To address this limitation on the data rate, the present invention provides a method of routing data to a mobile node within a communications network, comprising the steps of determining the location of a plurality of agent nodes from which data can be transmitted to the mobile node; and transmitting successive data units from a stream of data units intended for the mobile node to different respective ones of the agent nodes.

Next successive ones of the data units may be transmitted to the agent nodes on a round robin basis.

Alternatively or in addition, data units may be transmitted to the agent nodes based on an assessment of the availability of each agent node or the quality of the connection between each agent node and the mobile node. The quality of the connection may be assessed in terms of available bandwidth or specifically by considering the level of buffer use at each agent node.

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A datagram may be re-routed to a different agent node if the quality of the connection does not meet predetermined criteria, such as a minimum available bandwidth.

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A method according to the present invention is capable of providing a virtual bandwidth channel which is the sum of the bandwidths of the individual channels available between the agent nodes and the mobile node.

- 10 According to the invention, there is further provided a communications system for mobile data transfer, comprising a mobile node connectable to a foreign network away from its home network, a home agent node associated with the home network for receiving a stream of data units intended for the mobile node, a plurality of foreign agent nodes associated with the foreign network for
15 forwarding data units received from the home agent node to the mobile node, characterised in that the home agent node is configured to transmit successive data units from a received stream of data units to different respective ones of the foreign agent nodes.

20 Brief Description of the Drawings

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

- Figure 1a is a schematic diagram of the general arrangement of a mobile IP based
25 system;

Figure 1b is the diagram of Figure 1a showing the flow of data to a mobile node attached to a foreign network;

Figure 2 is a schematic block diagram showing the data flows within a prior art system;

- 30 Figure 3a is a schematic block diagram showing the data flows within a system according to the present invention; and

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Figure 3b is an example of a practical implementation of the system shown in Figure 3a.

Detailed Description

5 Figure 2 shows the prior art situation in which the mobile node 6 is within range of three foreign agents 10, 11, 12. When the correspondent node 9 sends a message comprising a sequence of datagrams P, Q, R ... Z to the mobile node 6, this message is intercepted by the home agent 7. The home agent 7 maintains a record of the current mobility bindings for the mobile node 6, from which it
10 knows the IP addresses of all of the foreign agents 10, 11, 12 with which the mobile node is registered. As each datagram is received, the home agent 7 produces the requisite number of identical copies of that datagram, in this case three, and encapsulates these with the respective care-of address of the foreign agents.

15 Each of the three identical copies of the received datagram is encapsulated with respective ones of three IP addresses corresponding to each of the foreign agents 10, 11, 12. The home agent 7 then tunnels the encapsulated datagrams to the respective foreign agents. The foreign agents 10, 11, 12 decapsulate the datagrams
20 and forward the three identical copies of the datagrams to the mobile node 6.

Figure 3a schematically illustrates the system according to the invention, the figures beside each link indicating an example data transfer capacity for that link. The foreign agents 10, 11, 12 may represent routers connected to ground-based
25 radio stations which maintain a radio link with a mobile computer 6 which is operating in the field disconnected from its home network. Alternatively, referring to Figure 3b, the foreign agents 10, 11, 12 may represent routers enabling connections over three different media types, for example, respectively, connection 13 to a wireless LAN over an infra-red link, connection 14 to an ISP
30 via a modem and connection 15 to a wireless LAN base station over a radio link.

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In a system such as the one illustrated in Figures 2 and 3, the lowest capacity links are likely to be those between the foreign agents 10, 11, 12 and the mobile node 6, particularly if these are wireless links. In the prior art transmission scheme, the maximum data rate between the correspondent node 9 and the mobile node 6 is therefore limited by the highest data rate on any one of the foreign agent - mobile node links. Assuming that the data transfer rates shown in Figure 3a are also applicable to the prior art system of Figure 2, the maximum data transfer rate in the prior art system is 28.8 kbps, being the data rate between foreign agent 11 and mobile node 6.

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Referring to Figure 3a, in the system according to the invention, the home agent 7 receives a message destined for the mobile node 6 from the correspondent node 9, as before. However, each datagram P, Q, R ... Z comprised in the message is not copied as it is received; instead it is immediately sent to the next available foreign agent. This may be done on a "round robin" basis, so that the first datagram P is sent to the first foreign agent 10, the second Q is sent to the second foreign agent 11 and the third R is sent to the third foreign agent 12. The fourth datagram S is then sent to the first foreign agent 10 and the process repeats for the remaining datagrams.

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As each encapsulated datagram is received by the respective foreign agent, it is then decapsulated and forwarded to the mobile node 6. The correspondent node 9 in Figure 3a may therefore send data at a composite rate which is the sum of the individual data rates for each of the foreign agent - mobile node links, namely $19.2 + 28.8 + 9.6 = 57.6$ kbps, ie. double the rate that is possible with the prior art arrangement in Figure 2.

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If the data rate between correspondent node 9 and home agent 7 exceeds the maximum possible data rate for the system, the resulting rate of data transfer to the mobile node 6 depends on a number of factors, one of the most significant being the underlying Internet protocol which manages the data transfer.

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Data transfer within the Internet may take place on a connectionless or connection-oriented basis, depending on the protocol used, which in turn depends on the nature of the service which is to be provided over the Internet.

5

Two of the best known data transport protocols are Transmission Control Protocol (TCP) and User Datagram Protocol (UDP), which are part of the TCP/IP Internet suite which also provides the Internet Protocol (IP). In known systems, TCP/IP is implemented in software, and is normally resident in, and an
10 integral part of, the computer operating system. User access to TCP/UDP through the operating system is comparable to similar processes such as user access to the computer's file system. A variety of TCP/IP implementations are commercially available for different platforms such as DOS and UNIX. For example, Microsoft TCP/IP software is provided as an integral part of the
15 Microsoft Windows 95 and Windows NT operating systems.

UDP provides a connectionless IP datagram delivery service which does not maintain an end-to-end connection between transmitting and receiving nodes and therefore does not guarantee data delivery. It merely treats each datagram as a
20 self-contained entity to be transferred on a best-try approach. It is up to the application using the UDP service to perform error checking; if it does not do so, it has no way of knowing if a datagram has arrived at the receiver or if it has been lost in transit. This form of transfer is particularly suitable for some types of data, for example image or voice data, where speed may be more important
25 than occasional errors, which are unlikely to substantially affect the received image or speech quality.

However, for many applications, a reliable connection-oriented service is required, which guarantees IP datagram delivery. TCP is a connection-oriented
30 protocol which maintains an end-to-end connection between transmitting and

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receiving nodes, and provides a reliable and secure logical connection for data transfer between the nodes.

TCP assumes that it can obtain a simple but potentially unreliable data service from the IP protocol layer. To turn this into a reliable service, it therefore has to provide a range of functions including (a) basic data transfer, (b) reliability and error correction, allowing recovery from damaged or missing data or data delivered out of sequence, and (c) flow control, which provides the receiving node with the means to govern the amount of data sent by the transmitting node. The TCP specification setting out the detailed requirements for implementation in each of these areas is available as RFC 793.

The system according to the present invention is particularly suited to UDP based tasks such as the transmission of image and voice data and will generate a significantly better data transfer rate as compared with the prior art system. If the maximum transfer rate over the foreign agent - mobile node links is insufficient to cope with the transfer rate between correspondent node 9 and home agent 7, UDP does not perform any form of flow control and simply drops data packets which exceed existing buffer capacities. It is therefore necessary to provide separate error checking facilities.

If the service being provided requires the use of TCP, a number of factors operate to produce a reliable, connection-oriented transfer. Since data is transferred over three separate links operating at different data rates, sequence control seeks to ensure that the datagrams arrives in the correct order. If the maximum data rate over the foreign agent - mobile node links is insufficient to cope with the transfer rate between correspondent node 9 and home agent 7, TCP receives information concerning undelivered or delayed datagrams. It acts on this information by decreasing the transfer rate on the correspondent node - home agent link so as to match the transfer rate on that link to the aggregate rate available over the foreign agent - mobile node links. However, the result of the



various factors which interact to produce overall TCP control is that it is difficult to predict the actual overall transfer rate, other than to say that this is likely to be better than the overall rate achievable with the prior art system. So, referring to Figure 3a, the maximum available data rate in a TCP based system is likely to lie somewhere between 28.8 kbps and 57.6 kbps.

In a practical system, the bandwidth of the foreign agent - mobile node links is difficult to predict, so to achieve optimal performance, modifications or alternatives to the round-robin algorithm can be used. In particular, before allocating a datagram to a particular foreign agent - mobile node link, it is desirable to determine whether the foreign agent is available, or to check the available bandwidth across the link. This can be done by, for example, checking the level of buffer use at each of the foreign agent routers. Checking the quality of the connection, and re-routing the datagram if the quality does not meet some predetermined criterion, such as a minimum bandwidth, helps to limit the possibility that a very low bandwidth foreign agent - mobile node link will become a new bottleneck in the data transfer process.

Mobile IP provides mechanisms for the mobile node to maintain its registrations, periodically checking for new foreign agents or that an already registered agent is no longer reachable. When the mobile node comes within range of further foreign agents, new registrations are initiated and datagrams may then be sent to those agents, so further increasing the potential data transfer rate. Similarly, when a foreign agent is no longer within range of the mobile node, the foreign agent will be de-registered and the incoming datagrams may be divided between the remaining agents.

Although the above examples have been described with reference to the Internet, the invention is applicable to any network based on the Internet Protocol and the principles may be extended to systems based on other network protocols.



Claims

1. A method of routing data to a mobile node (6) within a communications network, comprising the steps of:
 - 5 determining the location of a plurality of agent nodes (10, 11, 12) from which data may be transmitted to the mobile node; and
 - transmitting successive data units from a stream of data units intended for the mobile node to different respective ones of the agent nodes.
- 10 2. A method according to claim 1, wherein next successive ones of the data units are transmitted to the agent nodes on a round-robin basis.
3. A method according to claim 1 or 2, further comprising assessing the quality of the connection between each agent node and the mobile node prior
15 to transmitting a data unit to the agent node.
4. A method according to claim 3, including re-routing the data unit to a different one of the agent nodes if the connection quality does not meet predetermined criteria.
20
5. A method according to claim 4, wherein the predetermined criteria include a minimum bandwidth for the connection between an agent node and the mobile node.
- 25 6. A method according to any one of claims 3 to 5, wherein the available bandwidth for data transfer across the connection is a measure of the quality of the connection.
7. A method according to any one of claims 3 to 6, wherein the agent nodes
30 include data buffers and the level of buffer use is a measure of the quality of the connection.



8. A method according to any preceding claim, wherein each data unit is an IP datagram.
- 5 9. A method according to any preceding claim, wherein the agent nodes are foreign agents within a Mobile IP based network.
10. A method according to claim 8 or 9, wherein the stream of IP datagrams is received by a home agent (7).
- 10 11. A communications system for mobile data transfer, comprising:
a mobile node (6) connectable to a foreign network (2) away from its home network (1);
a home agent node (7) associated with the home network (1) for receiving a
15 stream of data units intended for the mobile node;
a plurality of foreign agent nodes (10, 11, 12) associated with the foreign network for forwarding data units received from the home agent node to the mobile node; characterised in that
the home agent node is configured to transmit successive data units from a
20 received stream of data units to different respective ones of the foreign agent nodes.
12. A method of routing data to a mobile node within a communications network, substantially as hereinbefore described with reference to the
25 accompanying drawings.
13. A communications system for mobile data transfer substantially as hereinbefore described with reference to the accompanying drawings.

