Multihop Wireless IEEE 802.11 LANs: A Prototype Implementation

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***abstract*—In this paper, we present a prototype for a new architecture, MCN (Multihop Cellular Network), implemented over a wireless LAN platform. MCN preserves the virtue of traditional single-hop cellular networks where the service infrastructure is constructed by many bases, but it also adds the flexibility of ad-hoc networks where wireless transfer through mobile stations in multiple hops is allowed. MCN can reduce the number of required bases or improve the throughput performance. On IEEE 802.11 compliant wireless LAN products, a bridging protocol, our BMBP (Base-driven Multihop Bridging Protocol), runs between mobile stations and access points to build bridging tables. The demonstration shows that MCN is a feasible architecture for wireless LANs.**

***Index Terms*— multihop, cellular, ad-hoc networks, packet radio, wireless LAN**

1 INTRODUCTION

The technologies and services of wireless communication have evolved rapidly during the past decade. These services can be divided into two major types [1]: voice-oriented and data-oriented. The former can be further divided into two categories: (1) high-power, wide-area cellular systems, such as GSM (Global System for Mobile communications) [2], and (2) low-power, local-area cordless systems, such as DECT (Digital European Cordless Telephone) [3]. The data-oriented services can also be divided into two categories [1]: (1) low-speed, wide-area systems, such as CDPD (Cellular Digital Packet Data) [4], and (2) high-speed, local-area systems, such as HIPERLAN (Hi Performance Radio Local Area Network) [5] and IEEE 802.11 [6].

Most of the services mentioned above are based on architectures with single-hop cellular networks (SCN). In fact, there is another kind of networks; namely, packet radio or ad-hoc networks [7, 8], in which no bases are needed. One of the advantages of these networks is low cost because no infrastructure is needed, and the networks can be deployed instantly.

In [9], we propose a new architecture, Multihop Cellular Network (MCN), which combines the features of SCN and ad-hoc networks. To demonstrate the feasibility of MCN architecture, we develop a prototype of MWLAN (Multihop Wireless Local Area Networks), which is based on the IEEE 802.11 compliant wireless LAN products developed by CCL, ITRI[1]. Note that MWLAN is an example of MCN. A bridging protocol, BMBP (Base-driven Multihop Bridging Protocol), is implemented such that mobile stations can access Internet through access points probably in multiple wireless hops.

The rest of the paper is organized as follows. In section 2, we describe the architecture of MWLAN. The design of our bridging protocol, BMBP, is presented in section 3. Section 4 details the hardware and software architectures of our MWLAN prototype. Section 5 demonstrates multihop bridging among mobile stations. Finally, conclusion and future work are given in section 6.

2 ARCHITECTURE

MWLAN, in which access points and mobile stations are not always mutually reachable in a single hop, is an example of MCN. One key feature of MWLAN is that mobile stations can communicate directly with each others, or even via other mobile stations, which leads to multihop routing.

A bridging protocol, BMBP (Base-driven Multihop Bridging Protocol), which is presented in the next section, runs between mobile stations and access points to build bridging tables. The access point which computes

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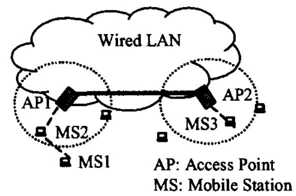


Fig. 1: A bridging example in MWLAN.

Destination MAC	Destination IP	Destination Sequence Number	Next-hop Mac	Hop count	Local System Clock

Fig. 2: The structure of bridging tables.

the bridging table for a mobile station is the one with which the mobile station is *associated.* A mobile station may be associated with more than one access point at the same time. In the case where a source has kept an entry in bridging table for a destination, packets may be bridged toward the destination by others. Otherwise, packets will be sent to one of the associated access points, probably in multiple hops. Then, also through the BMBP, the access point can find the other access point with which the destination is associated. From there, packets can be forwarded to the destination probably in multiple hops again. Fig. 1 gives the bridging path when the source, MS1, does not keep an entry for the destination, MS3. The dashed lines indicate the wireless path, and the solid line represents the backbone path which is wired in our MWLAN.

3 DESIGNING BASE-DRIVEN MULTIHOP BRIDGING PROTOCOL (BMBP)

The main object of BMBP is to build a bridging table at each node which could be an access point or a mobile station. Fig. 2 shows the structure of bridging tables, where the value of DSN (Destination Sequence Number) field is generated by the destination and is used to prevent loops [10]. Also the Local System Clock is stamped by each mobile station when it receives the bridging table from the associated access point, and is used to avoid out-of-date entries. The table also records the next hop and hop count to the destination. Four message types are needed to implement the protocol: *Beacon*, *Hello*, *Bridge*, and $Care-of$.

A. Protocol Messages

Beacon Message

Fig. 3 shows the format of Beacon messages, which are periodically broadcast by the access point specified in the "AP Information" field.

Hello Message

Fig. 4 shows the format of Hello messages, which are periodically broadcast by mobile stations. We define $Nhops$ as the maximum hop count that a Hello message can be propagated. The value of "N: Entry Count" field indicates the number of entries contained in the message and is limited to the value of $Nhops$ to reduce the vulnerability of wireless paths. The "MS1 Information" field contains the IP address, MAC address, and Sequence number of the mobile station who first fires this message. Similarly, the "MS i Information" field is stamped by the ith mobile station that sees this message.

Mac Header	Type (Beacon)	AP Information		
		IP	Mac	Seq.

Fig. 3: The format of Beacon messages.

Mac Header	Type (Hello)	N: Entry Count (1~*Nhops*)	MS 1 Information			MS 2 Information			...	MS *Nhops* Information		
			IP	Mac	Seq.	IP	Mac	Seq.		IP	Mac	Seq.

Fig. 4: The format of Hello messages.

Bridge Message

Fig. 5 shows the format of Bridge messages. This message contains the bridging table, computed by the access point specified in "AP Information" field, for the mobile station specified in "Destination's Information" field. The "N: Entry Count" field indicates the number of bridging table entries contained in the message. Each entry comprises 5 fields, (destination's IP, destination's MAC, destination's sequence number, next hop's MAC and hop count), so that the mobile station using this table knows the hop count to the destination and the next hop to forward packets.

Care-of Message

Fig. 6 shows the format of Care-of messages, which indicates the access point that the specified mobile station is associated with.

Note that the MAC addresses contained in the Mac Headers of Beacon and Hello messages are set in broadcast mode, while others contained in Bridge and Care-of messages are set in unicast mode.

B. Protocol Procedures at Mobile Stations and Access Points

Beacon messages are received by the mobile stations which can communicate directly with the access point specified in the message. Therefore a new entry, specifying how to bridge to the access point, can be added into the bridging table of the mobile station. Fig. 7 gives the

Mac Header	Type (Brdige)	AP Information			N:Entry Count	Destination's Information			Bridging Entry 1	...	Bridging Entry N
		IP	Mac	Seq.		IP	Mac	Seq			

Bridging Entry i →

Dest. i's Information			next hop's MAC	hop count
IP	MAC	Seq.		

Fig. 5: The format of Bridge messages.

Mac Header	Type (Care-of)	AP Information			MS Information		
		IP	Mac	Seq.	IP	Mac	Seq.

Fig. 6: The format of Care-of messages.

```
Procedure MS_Beacon
Begin
  entry=(AP.IP, AP.Mac, AP.seq, AP.Mac, 1, Local System Clock);
  if the entry for the Beacon.AP already exists in Bridging Table
  then update the entry
  else append the entry to Bridging Table
End
```

Fig. 7: The activated procedure when a mobile station receives a Beacon message.

pseudo code to process a Beacon message.

When a mobile station receives a Hello message, the value in "N: Entry Count" field is first checked. If the value equals the value of *Nhops*, the message is ignored. Otherwise, the mobile station checks if its information is ever recorded in the message. If yes, which means the message is looped back, it is also ignored, or the station will append its information to the message and increase the value of "N: Entry Count" by one. Then the mobile station will re-send this modified Hello message. The pseudo code to process a Hello message at mobile stations is given in Fig. 8.

The order of the mobile stations recorded in a Hello message reveals the upstream/downstream connectivity between these mobile stations. Therefore, the access point can compute partial bridging tables of these mobile stations. Then the computed results, packed in the Bridge messages, are sent to the mobile stations, probably in multiple hops, beginning from the nearest mobile station, i.e. one hop away, up to the farthest mobile station. Fig. 9 gives the pseudo code for an access point to process a Hello message. Note that the first mobile station recorded in the message has the largest value of hop count. Thus, the "for" loop in the pseudo code starts from the *last* entry in the Hello message. This processing order is important because the Bridge messages for farther mobile stations need to be forwarded by the nearer mobile stations which then should have their bridging tables in place first.

When a mobile station receives a Bridge message, it checks whether the bridging table recorded in the message belongs to it. If yes, the mobile station replaces its bridging table with the new one, otherwise it forwards the message to the next hop for the destination recorded in "Destination's Information" field. The pseudo code is presented in Fig. 10.

```
Procedure MS_Hello
Begin
  if ( Hello.N:Entry Count == Nhops )
  then does nothing
  else if ( MyIP appears in the Hello message )
       then does nothing
       else begin
              append MyInfo to the Hello message;
              Hello.N:Entry Count++;
              broadcast the updated Hello message;
            end
End
```

Fig. 8: The activated procedure when a mobile station receives a Hello message.

```
Procedure AP_Hello
Begin
  for i = "Hello.N: Entry Count" downto 1
  Begin
    /* compute the bridging table of the mobile station Hello.MS i */
    for j=1 to i-1
      entry j = (Hello.MS j.IP, Hello.MS j.MAC, Hello.MS j.Seq, Hello.MS (i-1).MAC, i-j)
    for j=i+1 to "Hello.N:Entry Count"
      entry j-1 = (Hello.MS j.IP, Hello.Ms j.MAC, Hello.MS j.Seq, Hello.MS (i+1).MAC, j-i)
    pack the result in a Bridge message
    transmit the Bridge message
  End
End
```

Fig. 9: The activated procedure when an access point receives a Hello message.

```
Procedure MS_Bridge
Begin
  if ( Bridge.Destination's Mac ≠ MyMac )
    forward this message to next hop
  else
    replace the local bridging table with the new one
End
```

Fig. 10: The activated procedure when a mobile station receives a Bridge message.

When an access point receives a Care-of message, it records the care-of address of the mobile station recorded in the message. The pseudo code is shown in Fig. 11.

4 Implementation

Besides BMBP, one little function of sending a string to some specified mobile station is also implemented to demonstrate the usability of computed bridging tables. The implementation is divided into two parts: access point and mobile station. The operating system for the notebook-based mobile station is Windows 95 while the MultiTask! real-time operation system is used on the desktop-based access point. To keep the CCL drivers unchanged, BMBP is implemented in the application layer. The access point is implemented on the platform provided by CCL, ITRI.

A. Access Point

The access point is an industry-standard personal computer with an 80486 microprocessor and two network adapters. One adapter is NE2000 compatible, connecting IEEE 802.3 wired LAN, and the other is LAN-to-Go, a product of CCL, connecting IEEE 802.11 wireless LAN. The NE2000 compatible adapter continuously

```
Procedure AP_Care-of
Begin
  if the Care-of.MS is existed in care-of list
  then update the care-of address of Care-of.MS
  else insert a new entry to the care-of list
End
```

Fig. 11: The activated procedure when an access point receives a Care-of message.

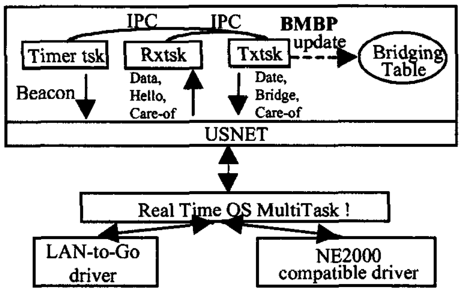


Fig. 12: System architecture for an access point.

intercepts packets transmitted on the wired network and examines the destination MAC address contained in the MAC header. If the MAC address belongs to the access point or one of its associated mobile stations, the packet is processed further. In the latter case the access point plays the role of a forwarder where the packet is replicated by the driver of LAN-to-Go adapter and transmitted through the wireless medium. Packets intercepted in the wireless LAN are processed by the access point in the same manner.

Fig. 12 shows the software architecture which can be divided into three parts: (1) In order to offer several services simultaneously, such as ftp, tftp and telnet, a Real-Time Operating System (RTOS) named MultiTask! is used to provide multitask switching. (2) The USNET [11] is a library that supports network protocols, such as TCP, UDP, IP, ICMP, ARP and RARP. (3) Three user tasks, Timertsk, Rxtsk and Txtsk, are defined to implement BMBP. Timertsk is responsible for transmitting Beacon messages periodically. Rxtsk is responsible for receiving packets, including Hello and Care-of messages, and the demonstrating packet containing one string. Txtsk is responsible for transmitting packets, including Bridge and Care-of messages, and the demonstrating packet containing one string.

B. Mobile Station

Fig. 13 shows the system architecture of a mobile station which is implemented on the platform of Windows 95. In addition to the LAN-to-GO driver, we also work with a driver, RAWETHER, from CCL, ITRI. The Lan-to-Go driver operates in promiscuous mode and forwards all pass-by packets to RAWETHER. The only difference between RAWETHER and other drivers is that RAWETHER processes all pass-by packets and preserves the MAC headers of the packets, while others only process the packets destined to them. Therefore, those packets need to be forwarded by a mobile station will not be filtered out and BMBP is thus workable.

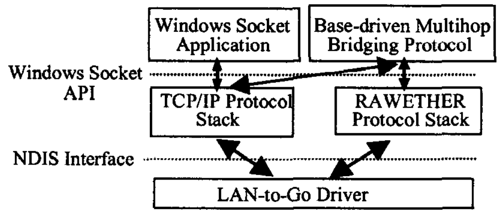


Fig. 13: System architecture for a mobile station.

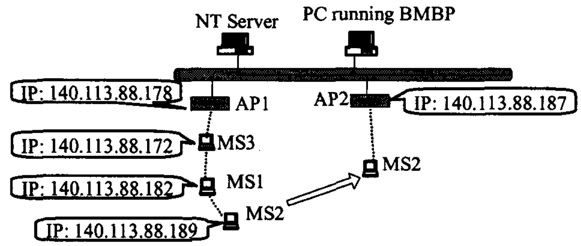


Fig. 14: Demonstration environment.

5 Demonstration

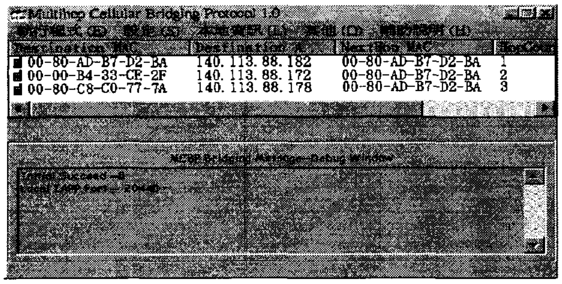
Two features of our MWLAN are important to demonstrate that BMBP is feasible. One is the ability of multihop routing. For the example in Fig. 14, MS1 should help MS2 to forward packets to MS3. The other is the ability of roaming. In the same example in Fig. 14, when MS2 is re-associated with AP2, it should still be able to send packets to MS3. Note that the value of *Nhops* is set to three in this demonstration. The IP addresses of AP1, AP2, MS1, MS2, and MS3 are configured as the ones in Fig. 14.

Fig. 15 dumps the bridging table and data frames at MS2. The bridging table of MS2 indicates that MS1 is the next hop to MS3, and the hop count to MS3 is 2. The frames show that MS2 had sent four data packets to MS3 and received four replies from MS3.

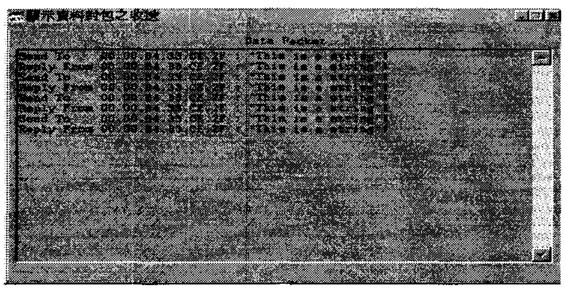
Fig. 16 dumps the bridging table of MS2 and the data frames sent between MS2 and MS3, after MS2 is re-associated with AP2. The frames illustrate that MS2 had sent two data packets to MS3 and received two acknowledgement packets from MS3.

6 Conclusion and Future Work

In this paper, we have presented our prototype implementation of a MWLAN (Multihop Wireless LAN) which is an example of a more general architecture, MCN (Multihop Cellular Network) [9]. The key component in our design is the bridging protocol, BMBP (Base-driven Multihop Bridging Protocol), running on access points and mobile stations to enable multihop routing and roaming. The prototype has demonstrated the feasibility of the MWLAN architecture. AS WLANs evolve towards

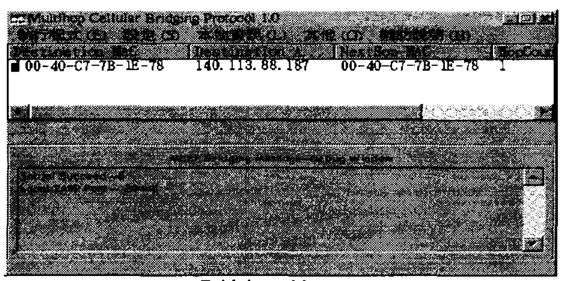


Bridging table

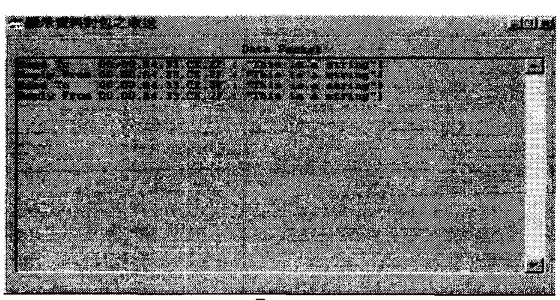


Frames

Fig. 15: Bridging table and frames at MS2.



Bridging table



Frames

Fig. 16: Frames sent by MS2 and the corresponding acknowledgement frames.

higher bit rate and shorter coverage, we can expect that the need for multihop wireless routing and roaming begins to grow.

Our BMBP is currently implemented in the application layer so as to avoid modifying the drivers. Plans are undertaken to embed the protocol into the driver level. Meanwhile, a distributed version of the bridging protocol called DMBP (Distributed Multihop Bridging Protocol) is being developed. A distributed bridging protocol has the advantages of better fault tolerance, regarding access points, and less-concentrated control traffic, although the computational overhead is shift from access points to mobile stations.

Finally, the feasibility of realizing the MCN architecture in the wide area cellular systems can be explored. If a mobile handset forwarding the traffic from the other mobile handsets can accumulate some sort of credit or rebate, a user might be willing to forward traffic for others, regardless of the state of the handset being active or stand-by.

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