Voice over Wireless LAN via IEEE 802.16 Wireless MAN and IEEE 802.11 Wireless Distribution System*

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Abstract

Today, IEEE 802.11 Wireless LANs (WLAN) have been widely deployed to provide wireless broadband access in local areas such as campuses or offices. Most of the WLANs are connected to the backbone via a wired distribution system (DS). IEEE 802.16 Wireless MANs (WMAN) aim to extend the wireless broadband access up to kilometers to facilitate the long-range "last-mile" solution. For short-range extension, IEEE 802.11 Wireless Distribution System (WDS) can be set up easily by connecting Access Points (AP) together to form multi-hop networks. This provides a quick, easy and low-cost solution up to hundreds meters. In this paper, we exam the capacity challenges in delivering voice traffic over WLANs which are connected to 1) IEEE 802.16 WMAN and 2) IEEE 802.11 WDS. For 1), we show that the capacity is limited by the WLAN bottleneck and we propose a multiplex-multicast (M-M) scheme [1] to double the capacity. For 2), we show that the M-M scheme should also be adopted in WDS. This scheme can sufficiently improve the voice capacity up to 7 times (from 3 to 22 voice sessions) in a 4-hop WDS. To verify our simulation results in [2], we set up a real multi-hop WDS. Experimental measurements confirm that our proposed scheme can increase both the voice capacity and service coverage of WDS.

1. Background

Conventional VoIP scheme transmits packets to/from each client individually over the wireless channel in a WLAN. Since each VoIP packet is a very small packet (typically 10-30 Bytes), the overhead at the PHY and MAC layers becomes quite significant, substantially reducing efficiency. Further exacerbating the situation is the large number of uncoordinated VoIP packets from different sessions that may contend with each other for channel access. The net effect is that the number of VoIP sessions (VoIP capacity) that can be supported becomes severely limited and the tight delay required for good voice service may not be achievable [2].

A multiplex-multicast (M-M) scheme previously proposed by us [1] can improve the VoIP capacity in a WLAN operated as an infrastructure basic service set (BSS) by close to 100%.The main idea of the M-M scheme is to combine downstream VoIP packets into a single packet for multicast over the BSS. This reduces the overhead of multiple VoIP packets, and it has been shown that the VoIP capacity can be improved by close to 100%.

As illustrated in Fig. 1, in the M-M scheme, a multiplexer (MUX) at the voice gateway combines multiple VoIP packets into a single multiplexed packet [3], and multicasts the multiplexed packet to the wireless end stations through the AP using a multicast IP address. The demultiplexer in each end station extracts its respective data and forwards them to the VoIP application.

Reference [1] provided an in-depth analysis of the VoIP capacity. For GSM 6.10, the M-M scheme can support 22 simultaneous voice sessions on an 802.11b WLAN. This nearly doubles the capacity of 12 in the conventional VoIP scheme [4] for the same delay and packet loss rate requirements.

In this paper, we exam the voice capacity limit when a WLAN is connected to a WMAN and/or a WDS. We show that the M-M scheme can sufficiently improve the capacity and extend the service coverage.

* This work was sponsored by the Areas of Excellence scheme established under the University Grant Committee of the Hong Kong Special Administrative Region, China (Project Number AoE/E-01/99).

Our real-life experimental measurements confirm our simulation results in [2] and this proves our theoretical solutions can be put into practice.

There are two major versions of the IEEE 802.16 standards: 1) IEEE 802.16-2004 standard [5] and 2) IEEE 802.16e standard. For 1), it is mainly designed for outdoor fixed wireless access in which antennas of base stations and subscriber stations are mounted to roofs or masts for signal transmissions and receptions. For 2), it is an amendment to 1) and aims to provide portable services to mobile clients. With 2), individual users can directly communicate with the WMAN. Since 2) is expected to be ratified in 2006 [6], in this paper, we assume the use of 1) which has already been standardized.

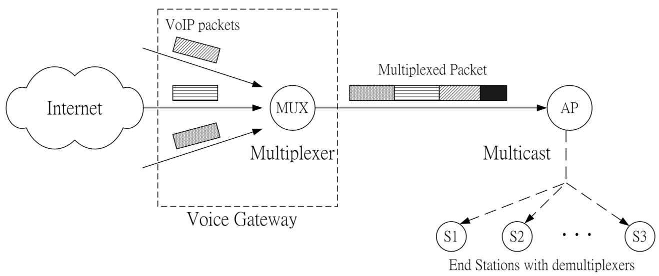

Figure 1. The M-M Scheme in Infrastructure BSS

The rest of the paper is organized as follows. In Section 2, we estimate the voice capacity of a WMAN. Section 3 exams the capacity bottleneck when a WLAN connected to a WMAN. In Section 4, we present experimental measurements that confirm our proposed scheme can boost the voice capacity and service coverage in WLAN connected to WDS. Section 5 gives an example in combining WLAN, WDS and WMAN to provide voice services over various distances. Section 6 concludes this paper.

2. Voice over Ethernet via IEEE 802.16 WMAN

WMAN is a "last-mile" wireless broadband solution. It brings broadband access to remote buildings or areas. Users in these areas can connect to the WMAN via conventional networks such as the Ethernet or WLAN [7]. Figure 2 shows an example in which a wired Ethernet network is connected to an IEEE 802.16 Wireless MAN (WMAN). The Base Station (BS) packs the incoming VoIP packets for several users into a downlink (DL) – burst and then transmits them to the Subscriber Station (SS) in a single DL-subframe as shown in Figure 3. The SS then extracts its packets and forwards them to the VoIP applications in the Ethernet. Similarly, the SS combines the upstream VoIP packets into an uplink (UL) – burst and transmits them to the BS in a single UL-subframe. The BS then extracts the original VoIP packets and forwards them to the Internet. The above process has similar functionality as the M-M scheme proposed by us in [1]. Both of them multiplex small packets into larger ones for transmissions so as to reduce the overheads induced by the MAC and PHY layers.

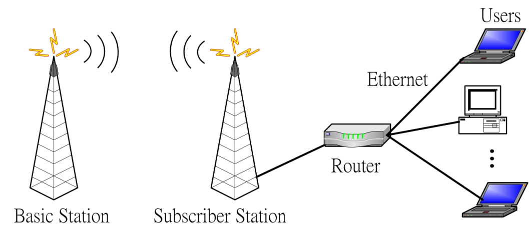

Figure 2. Voice Users in a WLAN connected to WMAN

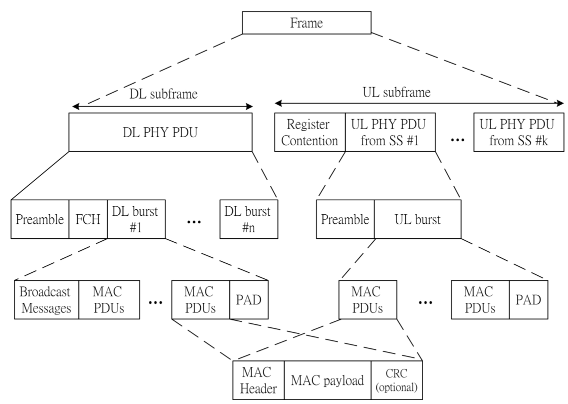

Figure 3. Frame structure of IEEE 802.16 TDD

Consider a point-to-point connection from a BS to a SS and we assume the same parameter settings (listed in Table I) of Time Division Duplexing (TDD) as shown in [8]. Let C be the maximum number of VoIP sessions that can be supported by IEEE 802.16 point-to-point connection.

$$T \approx 2 * P + B + RC + 2 \cdot C \cdot (V + MAC) \quad (1)$$
$$C \approx 60$$

where T is the transmission time of a fixed-size frame, P is the transmission time of the preambles, B is the transmission time of broadcast messages, RC is the register contention time, $V + MAC$ is the transmission time of a voice payload with MAC header. Since a VoIP session is a bi-directional traffic stream, thus each frame contains one upstream and one downstream voice payload. The above equations are approximations as parameter settings may vary in different implementations and be modified in future IEEE 802.16 standards [5].

TABLE I. PARAMETER SETTINGS OF IEEE 802.16 TDD

Number of Subscriber Station	1
Preamble + FCH (P)	3us
Broadcast messages (B)	10us
Register Contention (RC)	1us
Fixed frame size (T)	1ms
Voice packet size (V)	7.2us (45bytes)
MAC Header (MAC)	0.96us (6bytes)
PHY rate	50Mbps
VoIP Session Capacity (C)	≈ 60

To further reduce the overheads induced by the MAC layer, a possible solution is to adopt the multiplexing scheme in WMAN. However, it only slight improves the capacity. Imagine multiplexers are installed to combine the VoIP packets into a single packet before delivering them to the BS and SS for transmissions. Let C_{MUX} be the maximum number of VoIP sessions that can be supported by the IEEE 802.16 point-to-point connection with the use of multiplexing.

$$T \approx 2*P + B + RC + 2\cdot C_{MUX}\cdot V + MAC \qquad (2)$$
$$C_{MUX} \approx 68$$

The voice session capacity only slightly increases from 60 to 68 after using the multiplex scheme. It may not worthwhile to adopt this strategy too boost VoIP capacity. However, in the Section 3, we will show that this strategy can sufficiently improve the VoIP capacity of Wireless LAN connected to WMAN.

3. Voice over WLAN via IEEE 802.16 WMAN – Long Range Extension

The WLAN has been widely deployed to provide wireless broadband access in local areas such as campuses and offices. However, its coverage is limited to hundreds of meters (e.g. from 232m to 550m [9]) which is insufficient to support the "last-mile" wireless broadband solution. With IEEE 802.16, a WLAN can connect to a WMAN and this can extend the wireless broadband service to kilometers (up to 50km [6]), especially in circumstances when long-distance cabling are difficult or costly.

Figure 4 shows an example. The transmission rate of WMAN (e.g., 148.6Mbps [10]) is much faster than that of IEEE 802.11 (11 to 54Mbps). In addition, the capacity of delivering voice packets in WMAN is sufficiently enhanced by packing small VoIP packets into bursts for transmissions. With the conventional VoIP scheme, an IEEE 802.11b WLAN can support only 12 voice sessions [4]. The 802.16 WMAN, on the other hand, can support 60 voice sessions as discussed in Section 2. Therefore, the VoIP capacity bottleneck is at the WLAN rather than the WMAN.

To boost the capacity, we suggest using the M-M scheme proposed in [1] to install a multiplexer between the WMAN and WLAN as illustrated in Fig. 5. For downstream VoIP traffic, the multiplexer combines multiple VoIP packets into a single multiplexed packet and the AP multicasts the multiplexed packet to the wireless end stations. Each end station then extracts its respective data for the VoIP application. This sufficiently increases the VoIP capacity of each WLAN from 12 to 22 sessions.

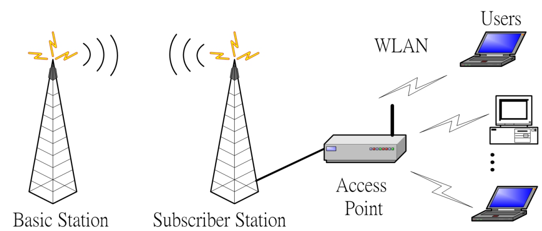

Figure 4. Conventional VoIP scheme in WLAN connected to WMAN

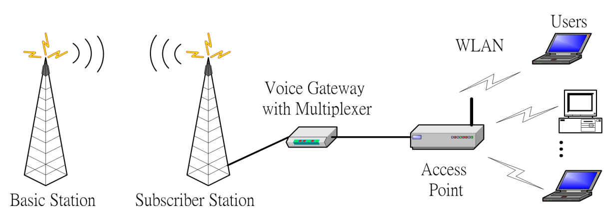

Figure 5. M-M scheme in WLAN connected to WMAN

4. Voice over WLAN via IEEE 802.11 WDS – Short Range Extension

A Wireless Distribution System (WDS) provides quick-and-easy network setup in areas that require temporary network services or where cabling is difficult. A WDS is basically a wireless multi-hop network, through which WLANs can be connected to the wired backbone. As shown in Fig. 6, the wireless multi-hop network comprises a number of interconnected APs, while the infrastructure BSS comprises an AP and client stations associated with the AP.

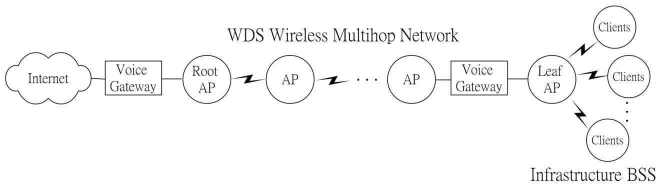

Figure 6. M-M Scheme in WDS

WDS can be used to extend the range of wireless service coverage. Since WDS uses IEEE 802.11, the distances between successive APs are limited to hundreds of meters (e.g. from 232m to 550m [9]) which is much smaller than the 1-hop transmission range (up to 50km [6]) of WMAN. Therefore, WDS can be deployed to provide short range coverage extension while WMAN for long range. An advantage of WDS over WMAN is its lower initial costs [6].

However, transmitting VoIP traffic over WDS to a WLAN in the straightforward way fails to fulfill the tight delay requirement, and severely limits the system capacity. Reference [2] extends the M-M scheme of [1] for WLAN connected via a WDS. Specifically, it showed that given a fixed delay requirement, the M-M scheme can increase the number of supportable VoIP sessions by ten times as compared to ordinary VoIP transmission over the WDS. In addition, with 22 VoIP sessions (max limit in an 802.11b infrastructure BSS connected via wired DS), simulations in [2] showed that the M-M scheme can achieve acceptable packet delays, (average of 27.1ms and standard deviation of 7.5ms) in a 10-hop WDS.

Figure 7. A 5-node multi-hop wireless network

To verify the simulation results in [2] with real-life experiments, we set up a 6-node multi-hop network with six symmetric DELL Latitude D505 laptop PCs with 1.5GHz Celeron Mobile CPU and 512MB RAM. Each node has a Buffalo WLI2-CF-S11 IEEE 802.11b Wireless LAN card (as shown in Fig. 7). All nodes run RedHat Linux 9 with HostAP [11] driver. To facilitate experimentation, we fixed the transmission power of each WLAN card to a small value (-38dBm), with basic and data rates set at 11Mbps. We obtained the transmission range of TxRange $\approx$ 2m and the carrier-sensing range of CSRange $\approx$ 5m=2.5*TxRange by following similar approaches as mentioned in [12]. We fixed the routing table of each node and set the distance between successive nodes to 2m.

We quantify the QoS of VoIP with two factors: 1) packet-loss rate and 2) delay performance. In this paper, we set the target packet loss rate P_{loss} to be no more than 1%, and the target packet delay of no more than 50ms. Specifically, we require the three-sigma delay (average delay + 3*standard deviation of delay) to be no more than 50ms.

With the M-M scheme, the total delay in the WDS multi-hop network includes the transmission delay between the root AP and the leaf AP, as well as the multiplex delay (MUX delay) incurred at the VoIP multiplexer. MUX delays are uniformly distributed between 0ms and the multiplexing interval, M, of the multiplexers. The average multiplexing delay, $M_{avg} = M/2$. Thus, the three sigma delay

$$S = D_{avg} + M_{avg} + 3(\sigma_{delay} + \sigma_{mux}) \tag{3}$$

where D_{avg} is the average transmission delay in the WDS multi-hop network, σ_{delay} is the standard deviation of the transmission delay, and σ_{mux} is the standard deviation of the MUX delay.

4.1. Experiment I: Conventional VoIP Scheme

The data sources are UDP traffic streams with fixed packet size of 45bytes (UDP/IP Headers + RTP Header + Data Payload). The small-sized packets from the same stream are separated by 20ms. The number of UDP streams from node 1 to node 5 and vice versa is the same so as to emulate bi-directional VoIP sessions.

Figures 8-10 show the experimental measurements in a 4-hop WDS. Using the conventional VoIP scheme, the WDS can support three VoIP sessions with 10.71ms (<50ms) three-sigma delay and 0.039% (<1%) average packet loss rate. However, adding an additional voice session (i.e. four voice sessions) increases the three-sigma delay to 22.32ms and the average packet loss rate to 23.8% which is unacceptable for real-time applications. This confirms the simulation results in [2] and shows that transmitting VoIP traffic over WDS in a straightforward way will severely limit the system capacity.

4.2. Experiment II: Multiplex-Multicast (M-M) Scheme

The data sources are UDP traffic streams with fixed packet size of 770bytes to emulate 22 multiplexed voice packets. The packets from the same stream are separated by 20ms which is the multiplexing interval assumed in [2]. There are two UDP streams, one from node 1 to node 5 and the other in opposite direction.

With the M-M scheme, the WDS can support 22 voice sessions with 31.6ms (<50ms) three-sigma delay and 0.02% (<1%) average packet loss rate. However, using the conventional VoIP scheme, delivering 22 voice sessions over a 4-hop WDS will result in 812.7ms three-sigma delay and 98% average packet loss rate which is again unacceptable for voice applications. Even in a 1-hop WDS, transmitting 22 voice sessions individually will induce 23.6ms three-sigma delay and 42% packet loss rate. These show that the M-M scheme can increase both the voice capacity and service coverage.

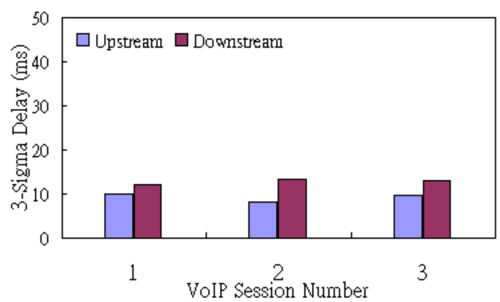

Figure 8. Three-sigma delays of three VoIP sessions in the 4-hop WDS

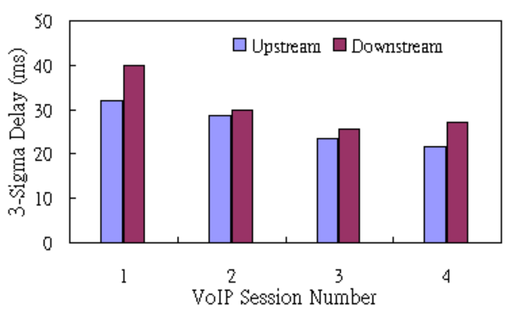

Figure 9. Three-sigma delays of four VoIP sessions in the 4-hop WDS

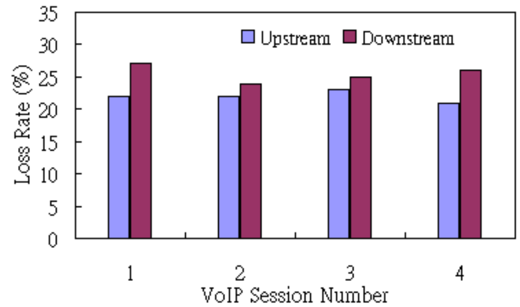

Figure 10. Average packet loss rates of four VoIP sessions in the 4-hop WDS

TABLE II. EXPERIMENTAL MEASUREMENTS FOR 4-HOP WDS WITH M-M SCHEME

	Upstream	Downstream
C (capacity)	22	
N (coverage)	4 hops	
M_{avg}	10 ms	
σ_{mux}	5.8 ms	
D_{avg}	1.34 ms	2.24 ms
σ_{delay}	0.65 ms	0.95 ms
S	30.70 ms	32.50 ms
P_{loss}	0.0067%	0.033 %

TABLE III. EXPERIMENTAL MEASUREMENTS FOR 4-HOP WDS WITH CONVENTIONAL VOIP SCHEME

	Upstream	Downstream
C (capacity)	22	
N (coverage)	4 hops	
D_{avg}	314.74 ms	544.89 ms
σ_{delay}	113.71 ms	141.57 ms
S	655.87 ms	969.60 ms
P_{loss}	97%	99%

TABLE IV. EXPERIMENTAL MEASUREMENTS FOR 1-HOP WDS WITH CONVENTIONAL VOIP SCHEME

	Upstream	Downstream
C (capacity)	22	
N (coverage)	1 hops	
D_{avg}	6.48 ms	6.91 ms
σ_{delay}	5.41 ms	5.85 ms
S	22.70 ms	24.46 ms
P_{loss}	41%	43%

5. Voice over WLAN via IEEE 802.16 and IEEE 802.11 WDS

In Section 2, we showed WMAN can support approximately 60 voice sessions and can provide long-range service extension. With the M-M scheme, the voice capacity of WLAN can be boosted to 22 sessions and WDS can provide short-range extension with adequate capacity, tolerable delay and loss rate. Their combinations can be used to set up wireless voice and data services over various distance requirements. Figure 11 shows an example, a multiplexer with M-M scheme can be installed between the long-range WMAN and WLAN/WDS to improve the capacity and provide tailor-made coverage extension.

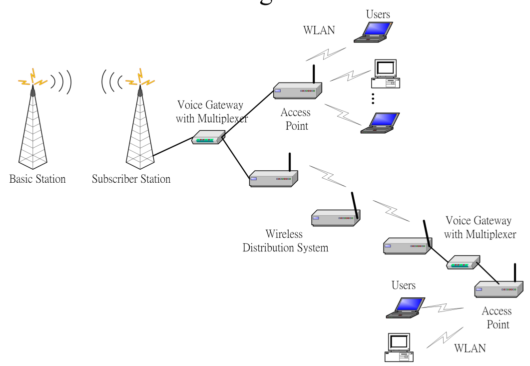

Figure 11. M-M scheme in WLAN connected to WDS and/or WMAN

6. Conclusion

This paper extends our previous work on a VoIP Multiplex-Multicast (M-M) scheme in infrastructure BBS to WMAN and IEEE 802.11 WDS. We have shown that the voice capacity of a WLAN connected to WMAN is severely limited by the WLAN and we have proposed the M-M scheme to double the capacity. In addition, our experimental measurements have confirmed the M-M scheme can sufficiently improve delay, capacity and coverage of VoIP over WDS. We believe M-M scheme is an attractive solution for deploying voice as well as data services when WLAN are connected to WMAN and/or WDS.

7. References

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