# Technologies Delivering Multiuser Transmission for Next-Generation IEEE 802.11 Wireless Networks

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**Introduction: The next generation of 802.11 wireless networks is near!**

As the latest standard for high throughput wireless local area networks (WLANs), IEEE 802.11n, reaches the final stages of its standardization process, the industry has begun to ponder the future after 802.11n. Timely so, shortly after 802.11n's draft text received its first positive response during the March 2007 ballot, the standards committee formed the Very High Throughput (VHT) Study Group (SG) to lead the investigation for a new WLAN specification aimed to deliver approximately double or more of 802.11n's performance.

Due to the tremendous opportunities this new wireless networking standard can promise, the industry has greeted this new endeavor enthusiastically. This is understandable since this standard may become a platform for exercising the many powerful research results that has come to light in the last few years since 802.11n first emerged. The SG may also be blessed with the allocations of new spectrum if there are collaborations with the mobile standard IMT-Advanced. Operations on new unlicensed frequency bands, like those higher than 5 GHz, are also being explored so that backwards compatibility with earlier versions of 802.11 WLANs may not be necessary. Moreover, the resulting VHT standard can target its design specifically for the various usage models unique of today or in a few years – for example, video-dominated Internet traffic – and thus opening up new market opportunities. The scope of this new standard is presently being defined by the VHT SG.

One of the first topics discussed in the SG's first few sessions is the method to achieve higher network performances. The SG has examined the simple notion of extending on the current MIMO-OFDM technologies used in 802.11n, namely by providing more channel bandwidth or adding more antennas. As pointed out [1], while these direct methods can achieve our goals and let us approach a wireless channel's theoretical capacity (i.e., its "Shannon limits"), we question whether they can actually be implemented feasibly. For instance, since it is uncertain whether the new standard would operate on new spectrum bands, the method of increasing channel bandwidths on the current band would require tedious coexistence protocols be defined to ensure fair medium sharing with existing 802.11a/b/g/n devices. Such protocols may potentially lower throughputs due to the extra overheads introduced. Or for example, the chipsets' computing powers may not be able to scale with the complexities associated with timely processing and decoding of the received signals of MIMO systems larger than 6x6 antennas. Therefore, in conjunction with said methods, new resources which can help efficiently achieve the VHT SG's objectives should be considered.

And maybe this is the reason why some SG members [2, 3] are proposing the idea of employing *multiuser diversity*, which exploits the spatial differences between each user's location in order to more effectively deliver data transmissions to them. Or more generally, as discussed in [2], it's to apply this concept to improve the performance of the widespread practice of *multiuser transmission* – the idea of transmitting to multiple users over the same frequency band at the same time. As have been demonstrated, these multiuser theories can be naturally extended onto MIMO and OFDM systems without significant increase in complexity. For example, multiuser-MIMO systems are emerging as part of the evolving 3GPP standards, like the PU2RC scheme [4]. The improvements in *spectral efficiency* achieved with multiuser-MIMO systems can be significant, especially as the number of users in the network increases [2]. Since spectral efficiency is a measure of the capacity to transmit data bit for each unit of frequency, in effect multiuser concepts can be the very resource to help dramatically raise the network throughputs of 802.11 networks and ease the need for having additional bandwidth or antennas.

While certainly the advanced idea of multiuser diversity is new in 802.11, the more general concept of multiuser transmission has in fact been proposed previously as a candidate technology for the next generation of WLANs. This idea was investigated a few years ago by one of Cornell University's students. After recognizing this gap in the current state of 802.11 technologies, then doctoral candidate Douglas Chan and his faculty advisor Toby Berger decided it is worthwhile to investigate the improvements that multiuser transmission schemes can provide for WLANs. The two's findings not only resulted into a few academic papers [5-7] but they also generated the first ever patent application that covers implementing multiuser transmission over a CSMA (Carrier Sense Multiple Access) network [8] and another that extends this idea to CSMA/CD (CSMA with Collision Detection) networks [9]. Subsequently Chan and his Cornell colleagues designed methods to implement backwards-compatible multiuser transmission on 802.11 networks, which of course are instances of CSMA networks, and proposed them to the 802.11 Wireless Next Generation Standing Committee at the September 2005 Interim Session [10]. In this proposal, Chan et al. showed the multifolded increase potential in network throughput with multiuser-based schemes. The proposal was received by the attendees with great enthusiasm at the time.

With the current advent of interests on multiuser wireless technologies for the next generation of 802.11 WLANs, this is a good junction to revisit that multiuser transmission proposal and at the same time consider the tremendous potentials promised by those two patent applications.

## Usage models for future WLANs

It is worthwhile to first speculate the types of usage models expected to be prevalent on WLANs in a few years. We can then focus the new standard to target these usages effectively.

One of the loudest buzzwords on the Internet these days has been video. In fact a recent survey [11] revealed that as high as 10% of all Internet traffic is constituted from just a single extremely popular video website alone! Because of video related Web streaming and downloads, since 2006 HTTP traffic has become the largest percentage of the Internet's traffic and is posed to grow even higher [11]. This trend indicates we should expect more users in the next few years to depend on their WLANs for video applications. But due to video applications' high demand for data rates, when multiple users are simultaneously requesting these services, their reliable and timely delivery to all users can put a strain on a network technology not designed sufficiently for such scenarios.

Since the introduction of high rate WLANs, especially with the emergence of draft-802.11n equipment, the industry has begun to see creative applications of WLAN for uses outside of connecting to the Internet. One of these is using WLAN as a home broadcast center of multimedia content, like TV signals from cable or a DVD player on a PC. With HDTV becoming the de facto video broadcasting norm in a few years, future WLANs designed to handle simultaneous high quality video streaming can open up lots of new market opportunities in this area. The personalized multimedia entertainment system on airplanes is such an example.

Another WLAN application gaining popularity is voice over IP (VoIP) calls. Yet unfortunately, the classical CSMA model that 802.11 is based on allows only one transmission over the medium (Fig. 1), so an access point (AP) does not support multiplexing more than one VoIP calls in each transmission over the air at any given time. In order to satisfy the tight latency constraints in voice calls, it is common for vendors to recommend the maximum number of concurrent calls that their APs can support. However, if the next WLAN standard can enable simultaneous transmissions over a WLAN, then the capacity of calls can be raised. Simultaneous transmissions may also let us finally achieve full-duplex communications on WLANs too.

Obviously, there are many more future WLAN usage models worth exploring as well. In collaboration with the WiFi Alliance, members of the VHT SG have been engaged in shortlisting the usage models for the next WLAN standard to focus upon.

**Multiuser transmission WLAN and its advantages**

For the future usage models just considered, it is easy to see how multiuser transmission can directly address their requirements. It succeeds so by being able to deliver each user's data packet across the channel at the same time and frequency band via a multiuser PHY layer. This idea for WLAN to employ a multiuser framework is an evolutionary advancement from the classical CSMA model used in current WLANs.

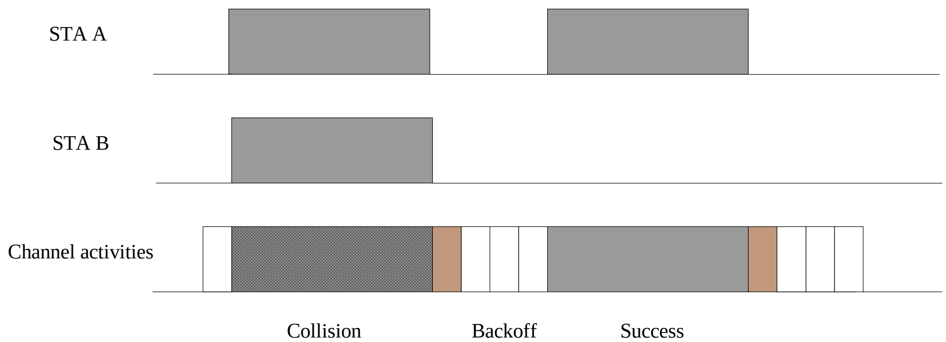


Figure 1: Example of channel activities with the classical CSMA model used in 802.11-based WLANs.

Because a channel has finite resources, enabling multiuser transmission can mean trading off on certain attributes, like spectral efficiency. But if a WLAN's multiuser PHY layer is designed so that a certain level of spectral efficiency is maintained, then the latency associated with delivering each user's packet can be shortened from that with the classical CSMA WLAN. Part of this improvement can be thought of as the gain contributed from lessening the overheads expended with scheduling the transmission by the WLAN's multiple access (MAC) protocol. This in effect increases the individual throughput attained by each user and ultimately raises the network's *aggregate throughput*. In other words, a WLAN performs better because its multiuser PHY layer can more efficiently exploit a communication channel's resources, like tapping into those wasted by the MAC layer.

In Chan et al.'s proposal to the 802.11 working group [8], they showed as illustrated in Figs. 2 and 3, that an 802.11a WLAN can increase its aggregate throughput by up to ten times with a multiuser physical layer! For example, in their scenario with an optimized MAC layer (Fig. 3), a multiuser scheme that maintains as low as a third of the regular 802.11a WLAN's spectral efficiency can still provide about four times increase of aggregate throughput. (Their results actually consider *goodput*, which is simply a variant of throughput that accounts only for the packet's data payload.)

A key idea from this proposal is also a method to remain backwards compatible with current WLAN standards. In the proposed scheme an AP can serve both 802.11-based client stations and those that are multiuser-enabled. This is accomplished by adding to the existing 802.11 MAC and PHY stack with a "multiuser detection/decoding" (MUD) layer which achieves its namesake (Fig. 4). Enhanced with this functionality, stations can continue to access the channel according to the present 802.11 MAC protocol, only that when two or more users transmit at the same time the intended receiver can separate and decode each user's data packet via the MUD technique of choice (Fig 5.).

The multiuser detection and decoding schemes they suggested in the proposal employ multiuser LDPC codes. However, it is not necessary to use such concepts to achieve multiuser transmission. For example, it would also work with an Orthogonal Frequency Division Multiple Access (OFDMA) PHY layer, which allocates subcarriers of a spectrum to signals belonging to different users. If OFDMA is applied, then its PHY layer can also retain the many desirable features of MIMO-OFDM that wireless standards nowadays embrace. Moreover, if multiuser transmission is indeed applied to extend 802.11n's MIMO-OFDM technology, then the multifold increase in goodput should well satisfy the requirements expected by the VHT SG for the next 802.11 WLAN standard.

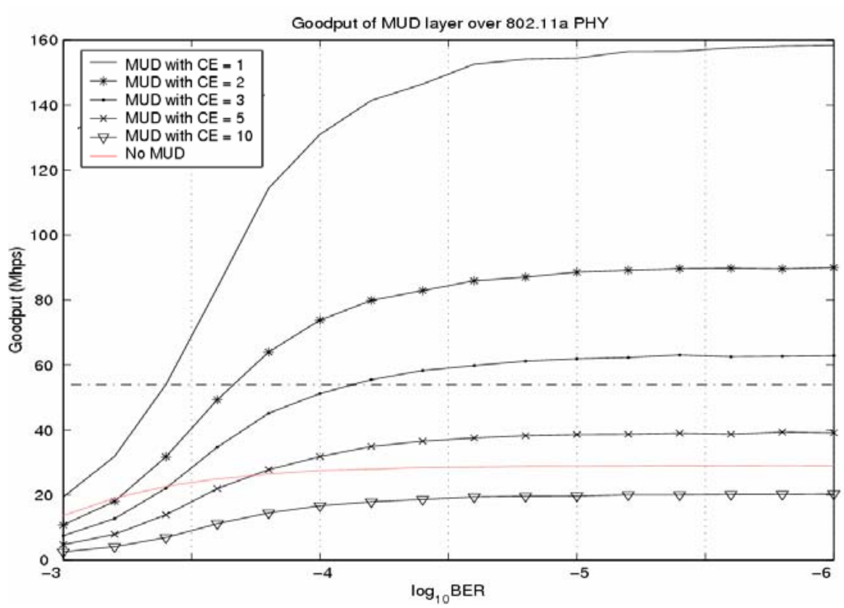


Figure 2: Performance of an 802.11a WLAN with a multiuser detection/decoding (MUD) capable PHY layer. CE represents the rate of the code used to achieve MUD. This shows that an 802.11a WLAN can increase its aggregate throughput by up to ten times with a multiuser PHY layer! [10]

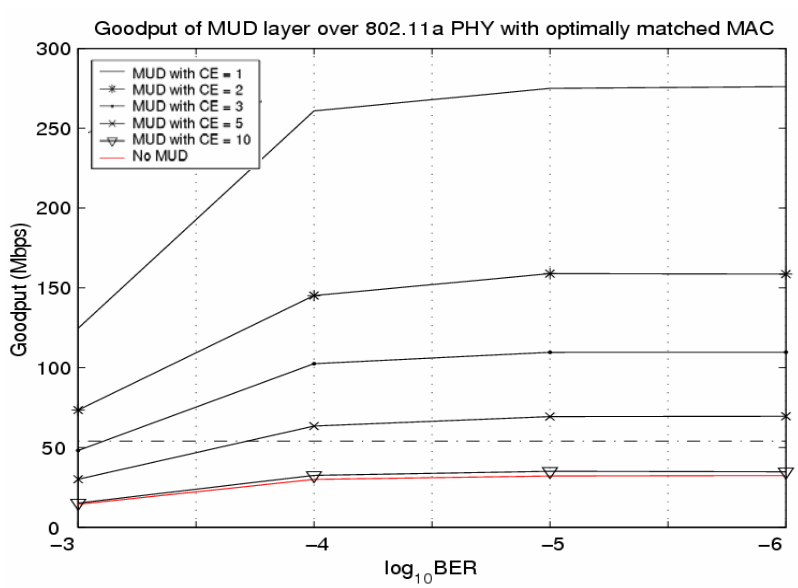


Figure 3: Performance of an 802.11a WLAN with a multiuser detection/decoding (MUD) capable PHY layer and optimized MAC layer. CE represents the rate of the code used to achieve MUD. This shows a multiuser scheme that maintains as low as a third of the regular 802.11a WLAN's spectral efficiency can still provide about four times increase of aggregate throughput. [10]

Other multiuser methods include applying joint decoding or successive interference cancellation schemes to separate each user's signals. The variety of ways to apply these concepts has given rise to a range of multiuser PHY layers each with different degrees of complexity and effectiveness depending on the type of wireless environment. Moreover, because they are not too abstract to be implemented practically, many ideas derived from these two concepts are already adapted by the 3GPP standards. In fact, the emerging generation of 3GPP standards has been considering methods enhanced with multiuser diversity too, like multiuser-MIMO (MU-MIMO). Since these schemes embody the positive effects of spatial diversity as well, they can provide even further performance gains than plain multiuser transmission PHY layers.

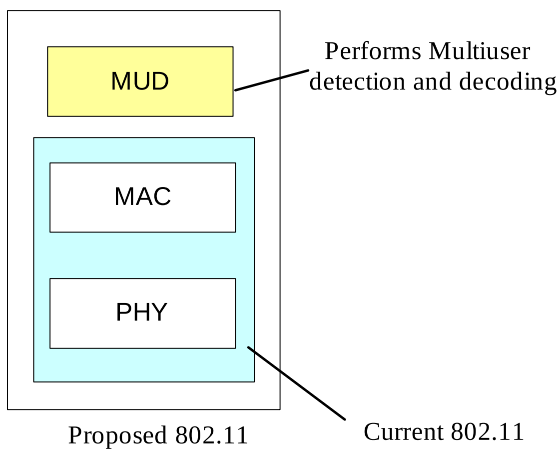


Figure 4: The multiuser detection/decoding (MUD) capable layer in the proposed multiuser 802.11 WLAN system.that can maintain backwards compatibility. [10]

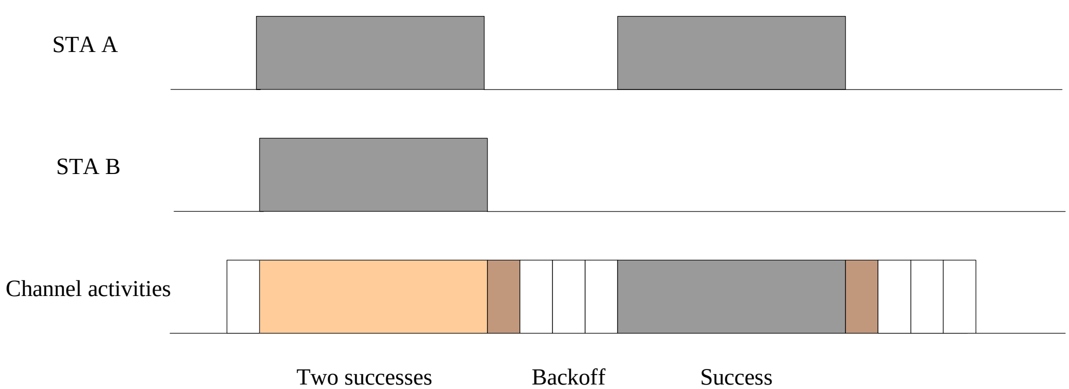


Figure 5: Example of channel activities with the proposed multiuser 802.11 WLAN system which continues to use the existing 802.11 MAC protocol. [10]

**Potentials of the first ever multiuser CSMA and CSMA/CD patents**

Clearly, along with adding antennas and channel bandwidth, multiuser transmission is an additional alternative for rising 802.11 WLAN's performance to the performance levels envisioned by the VHT SG. And as Chan et al.'s proposal [8] has illustrated, there are ways to integrate a multiuser PHY layer with the existing 802.11 framework so that backwards compatibility is upheld – specifically, the current 802.11 MAC protocol or even PHY layers (of 802.11a/b/g/n) can continue to be used.

Capturing these ideas is the first ever patent filed on multiuser CSMA networks: "Methods and Systems for Channel Sensing Multiple Access Communications with Multipacket Reception" [8]. (The term "*multipacket reception*" means simultaneously receiving packets of multiple users and is completely synonymous to the notion of multiuser transmission described here.) Within the scope of this disclosure is not only the framework of Chan et al.'s proposed scheme [10], but also variants of it that encourage new transmissions to start even when there're one or more already using the medium (Fig. 6). These variants may not necessarily be 802.11-backwards compatible, however, they may be able to provide even higher performance gains by allowing devices to continuously monitor the channel and determine the best opportunity to begin their transmissions in the presence of others [6]. These variant schemes can become candidate protocols for other wireless technologies or also for the next WLAN standard in the event that it does not require backwards compatibility.

By extending the multiuser transmission paradigm to include collision detection protocols, the first ever patent disclosure on multiuser CSMA/CD networks was created too: "Systems and Methods to Detect Collisions in Channel Sense Multiple Access Communications" [9]. In addition to realizing the same scope as its CSMA counterpart, the disclosure for multiuser CSMA/CD also includes a novel way to perform collision detection over wireless networks, a task that has been agreed in the past to be infeasible for the wireless environment [7].

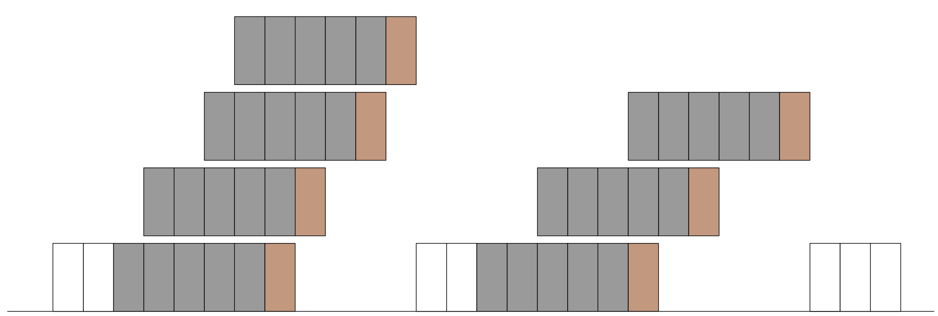

Figure 6: Example of channel activities with a variant multiuser transmission WLAN which encourages new transmissions to start even when there's one or more already occupying the medium. The number at the start of each packet represents the number of users transmitting at the same time. Channel activities are demarcated with slot boundaries.

It should be noted that the disclosure in [8] does not put any limits on the particular multiuser transmission method used. In other words, this patent application covers any CSMA-based network that uses a multiuser scheme, be the medium of wireless, fiber optics, copper, etc. Such generality significantly magnifies the values of [8] and [9] since their owner or licensee can continue to find applications for them outside of just WLANs. For instance, the patent can cover fiber optical CSMA networks using multiuser PHY layers like Dense Wavelength Division Multiplexing (DWDM), which facilitates transmissions of many wavelengths of laser light carrying different signals over a single optical fiber.

And of course, these two patents [8] and [9] can be used in conjunction with any *existing* intellectual properties (IPs) on multiuser transmission technologies too, thus bringing significant added values to their original worth. Not to mention, new methods and results are likely to be discovered in the process of developing a multiuser WLAN systems. So, naturally this can lead to terrific opportunities to further obtain new IPs on wireless communications and signal processing that are essential to the next WLAN standard and beyond. Therefore, in addition to its inherent worthiness, tremendous extended value can still be derived from [8] and [9] for being the centerpiece of a strategic and lucrative long-term 802.11 WLAN R&D program.

## Conclusions

When the next 802.11 standard emerges, new market opportunities for WLAN applications are expected to open up and continue to drive the demand for WLANs. Given such market growth, the underlying technologies central to achieving the new standard's performance goals will appreciate significant values. And as we approach the practical performance limits of current PHY layer techniques, multiuser transmission and multiuser diversity technologies are excellent methods to help attain the performance levels expected for the next 802.11 standard. Moreover, these multiuser techniques also have the ability of preserving the existing 802.11 protocols too. With all things considered, applying a multiuser PHY layer is the next natural and best step for the evolution of 802.11 WLAN standards towards becoming a superior wireless broadband solution. As VHT SG considers adapting a multiuser PHY layer, the pending patents [8, 9] discussed above can very likely become an integral part of the new standard's underlying framework, if not just an optional operating mode that provides performance enhancements whenever necessary. But in any case, owning these patents' rights can realize immense values.

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