Chapter 2
Recent Advances in Wireless Communications

In this chapter, we provide some necessary building blocks for the attachment transmission design and its applications, including the OFDM/OFDMA modulation primer and reviews of some novel PHY techniques for wireless communications. Then, at the end of this chapter, we also present a survey on some classic wireless network problems.

2.1 OFDM/OFDMA Preliminary

We first introduce the basic idea of an OFDM/OFDMA-based system. OFDM modulation has been developed into a promising technique for multi-carrier transmissions, which improves the network performance significantly for future wireless communications. OFDM transforms a frequency-selective wide-band channel into a group of nonselective narrow-band channels named subcarriers, which makes it robust against large delay spreads and cross-talk effect by preserving orthogonality in the frequency domain. Orthogonal Frequency-Division Multiple Access (OFDMA) is a straightforward extension of OFDM into a multiuser environment. It has a series of attractive features, including scalability, intrinsic protection against multiple access interference (MAI), as well as flexible resource management. Therefore, it is adopted in a wide range of systems, such as multiuser satellite communications [1] and fourth-generation cellular networks [2].

2.1.1 OFDM Basis

OFDM can be considered as a combination of multi-carrier modulation (MCM) and frequency shift keying (FSK) modulation [3]. MCM is an approach to data transmission that involves dividing the transmitting data stream into several parallel

L. Wang et al., *Attachment Transmission in Wireless Networks*,
SpringerBriefs in Computer Science, DOI 10.1007/978-3-319-04909-0_2,

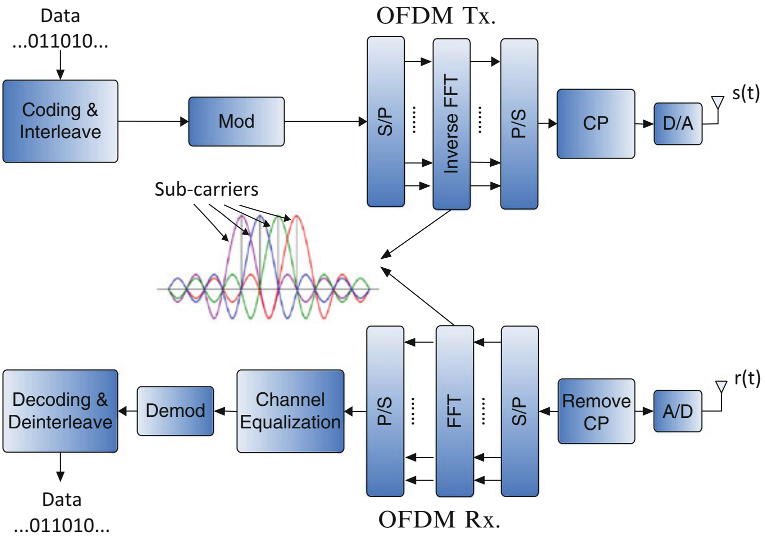

Fig. 2.1 OFDM modulation block diagram. The transmitted signal is spread and modulated across the subcarriers

bit streams. Each bit stream has a much lower data rate, and are modulated onto individual carriers or subcarriers. FSK modulation is a technique whereby data is transmitted through discrete frequency changes of a carrier wave. To achieve orthogonality amongst the carriers, it separates them by an integer multiples of the inverse of symbol duration of the parallel bit streams. When combining MCM and FSK together in OFDM, the entire allocated channel is occupied through the aggregated sum of the narrow orthogonal subbands.

We now detail the transmission procedure. On the transmitter side, the data to be transmitted on an OFDM signal is spread across the carriers of the signal, each carrier taking part of the payload. This baseband modulation is performed via an inverse Fast Fourier Transform (IFFT). To combat symbol misalignment due to multipath effects, OFDM has a built-in robustness mechanism called Cyclic Prefix (CP). Instead of using an empty guard space, a cyclic extension of the OFDM symbol fills the gap, which has a length that exceeds the maximum delay of the multipath propagation channel. After that, the signal sequence with CP is converted into analogue signals and then transmitted into air.

Upon receiving the signals, the receivers sample them and pass them to a demodulation process chain. After the sampling procedure, the sampled data blocks are processed by Fast Fourier Transform (FFT) process and the final result is the original data subject to certain scaling and phase rotations. These scaling and phase rotations are mainly due to channel dispersion. Therefore, channel equalization is needed to recover the original data from the distorted one. Figure 2.1 illustrates the basic structure of an OFDM communication system.

2.1.2 OFDMA Basis

OFDMA is a multiuser version of OFDM, which allows simultaneous low data rate transmissions from several Mobile Stations (MSs or clients). In 2002, OFDMA was adopted as the air interface for emerging IEEE 802.16e standards for Wireless Metropolitan Area Network (WMAN) [4]. In the OFDMA subcarrier structure, the subcarrier frequency spacing is fixed. To support a wide range of bandwidths, it simply adjusts the FFT size to the channel bandwidth. Therefore, the basic unit of physical resource is fixed and the impact on higher layers is minimized. This significantly improves the deployment scalability and flexibility and is one of the most essential features offered by OFDMA.

In an OFDMA-based network, the available subcarriers are divided into several mutually exclusive groups represented by subbands. Each group of subcarriers is assigned to one MS for concurrent transmission [5]. Signals from clients are separated in time and/or frequency domains. That is, the orthogonality among subcarriers ensures that clients are protected from MAI. In particular, time is partitioned into fixed length frames across all the subcarriers. A frame can be of length 2, 2.5, 4, 5, 8, 10, 12.5, or 20 ms [6]. This value depends on several factors, such as channel conditions and the duration of control information. The allocation for each client is performed in the unit of time × frequency, which is called a slot. Hence, multiple clients are allocated different slots in the time and frequency domain, that is, different groups of subcarriers and/or OFDM symbols are used to transmit the signals to/from multiple users. Each MS can have its own expected bit-rate and Service Level Agreement (SLA).

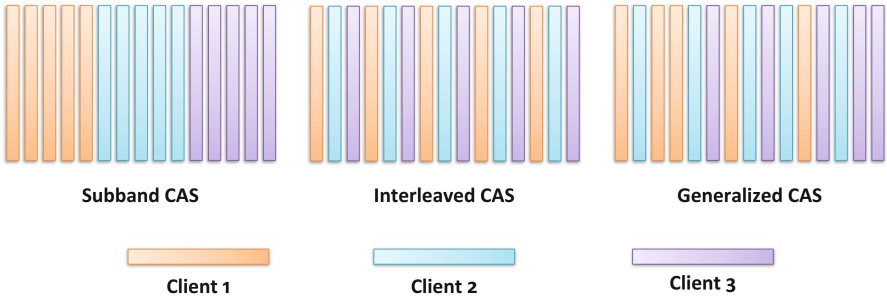

Fig. 2.2 Illustration of three commonly used subcarrier allocation schemes: subband CAS; interleaved CAS; generalized CAS

There are three commonly used carrier allocation schemes (CAS): subband CAS (SCAS); interleaved CAS (ICAS); and generalized CAS (GCAS). We illustrated these three allocation schemes in Fig. 2.2. SCAS means that all the subcarriers of each client are grouped together. In this way, receivers can easily separate the received signals by filter banks. The major disadvantage of SCAS is the inability to leverage frequency diversity. Therefore, the performance of a client could easily be affected by deep fading in some subcarriers. To solve this problem, the ICAS is proposed, which allocates the subcarriers with uniform spacings for different clients. However, since different clients experience different channel conditions and fading, there still exist certain limitations. To overcome the above limitations, GCAS, as the most flexible and desirable scheme, has emerged to meet clients' diverse subcarrier requirements. This allows users to select the best available subcarriers to transmit their packets, enabling the frequency diversity to be fully utilized. However, how to coordinate and negotiate between clients remains a great concern. Therefore, efficient coordination mechanisms are required to take advantage of generalized subcarrier allocation schemes and to achieve maximum throughput and minimize interferences.

2.2 PHY-Layer Assist Communication Paradigms

PHY layer techniques have been frequently used to assist MAC layer protocols in recent years. In [7], a PHY layer RTS/CTS is proposed for multi-round leader election. A PHY layer interference model is proposed in [8] for link scheduling. In [9], the author utilizes a PHY layer ACK to reduce the traditional link layer ACK overhead. Attachment Coding similarly shares the idea of PHY signaling, but differs from the above approaches in that it enables PHY layer control messages to be transmitted simultaneously with data traffic. Therefore, PHY layer control messages do not occupy the bandwidth of the original data traffic, and thus significantly reduces the control overhead. Side channel in [10] uses "interference pattern" for users to jam control information on other's data packets without IC, while FAST simply transmits control information on air and recovers the original data packets from the row signals, which is much more reliable and flexible. Our previous work *h*jam [11] adds jamming signals on other users' packets, in this way they can provide access requests for a certain authority in centralized networks. Therefore, it cannot be used in decentralized networks. In FAST, however, control information is simply transmitted in *Attachments*, which is independent to ongoing data packets. Therefore, it can provide flexible PHY layer information for higher layer protocols and is more suitable for distributed and unsynchronized networks.

2.3 Review of Classic Problems in Wireless Networks

At the end of this chapter, we present some classic problems in wireless networks to better understand the background of attachment transmission. These classic problems include the coordination approaches for wireless communication, multichannel allocation problem, as well as the hidden and exposed terminal problems.

2.3.1 Coordination Approaches for Wireless Communications

In order to address radio interference issues and reduce transmission collisions, a large amount of coordination schemes have been proposed. The existing approaches can be classified as out-of-band and in-band.

The out-of-band coordination approaches are more suitable for multichannel/radio environments. In these approaches, they often allocate a dedicated PHY channel to control messages [12, 13]. Stations switch in and off the control channel during transmissions, leading to significant switching overhead. In addition, these approaches consume an entire channel for control purpose only, which is too expensive. Recently, in [14] the channel contention is moved from the time domain to the frequency domain but requires extra antennas for listening purposes only.

The in-band approaches deliver the control traffic in the same channel as the data traffic. These approaches also consume the communication resources. In the current 802.11 legacy protocol design [15, 16], the coordination is scheduled along the temporal space, which introduces large overheads such as the DIFS, SIFS, and random back-offs. Some recent works also reveal the need for optimal CSMA by experimental results [17]. In [18], they propose a minimum controlled coordination by reducing the DCF overhead. However, in our hJam, we remove such coordination overhead. Also different from CDMA [19] using PN code in code space, our hJam exploits the opportunity in the frequency domain.

2.3.2 Multichannel Allocation Problem

Researchers have long been exploiting multichannel capacity in wireless networks. A lot of wireless standards support multiple channels for concurrent transmissions, such as WiMAX, sensor networks [20], and cognitive radio networks [21]. Traditional methods for multichannel allocation can be classified into four categories: dedicated control channel (e.g., DCA [22] and DPC [23]), split phase (e.g., MMAC [24] and MAP, as presented in [25]), common hopping (e.g., CHMA [26] and CHAT [27], and multiple rendezvous (e.g., SSCH [28]).

Dynamic Channel Assignment (DCA) in [22] is a representation of a dedicated control channel. The overall bandwidth is divided into one common control channel and n data channels. Each node is equipped with a second radio as a control radio, which will operate on the common control channel to exchange control information and to obtain rights to access the data channels. However, under a high traffic load, the control channel becomes a bottleneck. Common hopping is a sophisticated approach to solve the channel reservation problem and improve the channel utilization with single radio, such as Channel Hoping Multiple Accesses (CHMA) [26]. In CHMA, time is divided into small slots, each corresponding to one of the channels. All nodes hop together following a predefined pattern and negotiate their transmissions using the same channel. Whenever a sender/receiver pair agrees to transmit, they will stay in that channel for the rest of the period, while others keep hopping to the next channel. Common hopping has improved channel utilization when compared with dedicated control channel. However, precise synchronization is required among nodes, and switching time for channel hopping also brings considerable cost.

Previous solutions have the common drawback that all nodes waiting to transmit converge on the same channel. With only single rendezvous, the rendezvous channel can become a bottleneck when data packets are not much longer than control packets, or when a large number of channels are available. Thus a multiple rendezvous approach is proposed to overcome this bottleneck, such as SSCH [28]. Although time is still divided into slots as in common hopping, nodes maintain their own hopping patterns and wait for their intended receivers for transmission. This kind of approach effectively mitigates the congestion on the common control channel and is actually the rudiment of game theoretical approaches.

Adaptive subchannel allocation in [29] is the first work to treat resource allocation as an optimization problem for OFDMA. Since then, a considerable amount of research based on Game Theory has been conducted for channel allocation problems. The aim of game theoretical approaches is to balance users' interests, and thus the whole system performance can be improved. This class of approaches can eliminate common control channels in the above-mentioned research, and the coordination overhead can also be significantly reduced. The allocation protocol proposed by Mähönen and Petrova in [30] depends merely on transmission history, thus it greatly reduces the coordination overhead. However, short-term transmission history is not a very good interpreter to adapt channel access. Therefore, it only can achieve a throughput better than Multichannel ALOHA. Park and Van Der Schaar in [31] prove that with enough memory to store transmission history, users can achieve TDMA like performance. However, such memory requirement is too crucial for mobile stations. To achieve efficient multichannel allocation without coordination, Cigler and Faltings in [32] propose a multi-agent learning mechanism for distributed users, where a global coordination signal is predefined for learning. They do achieve Correlated Equilibrium for resource allocation games. However, the coordination signal cannot be easily obtained, and hence the sender/receiver negotiation is not considered in their work.

2.3.3 Hidden and Exposed Terminal Problems

There has been a considerable amount of research on hidden and exposed terminal problems in wireless networks, since these two problems significantly degrade the network performance. A common approach to solve both these problems is to use an RTS/CTS handshake [33], which is also known as "virtual carrier sensing." RTS/CTS handshake utilizes RTS/CTS exchanges to avoid collision in the case of a hidden terminal problem, and infer the transmission concurrency in the case of an exposed terminal problem. Extensive mechanisms then emerge based on the RTS/CTS handshake. MACA-P [34] enhances the RTS/CTS mechanism to increase transmission concurrency. It designs a control gap to synchronize RTS/CTS exchange between different node-pairs, while RTSS/CTSS [35] adds an off-line training phase before RTS/CTS exchanges to further explore transmission concurrency. However, the above RTS/CTS handshake-based mechanisms are not feasible in practice, since RTS/CTS handshake leads to a considerable overhead. Recent work named CMAP [36] proposes an online "conflict Map" to deduce exposed nodes. A special header/tailer is designed for receivers to figure out interferers, and thus allows exposed nodes to transmit concurrently. However, the hidden terminal problem still exists. Full duplex [37] proposes a practical busy-tune scheme to solve the hidden terminal problem, but the exposed terminal problem becomes more severe. Unlike the above approaches, FAST utilizes a PHY layer technique to provide useful Channel Usage Information for higher layers. Therefore, it can solve both the hidden and exposed terminal problems in a cost-efficient way.

References

1. L. Wei and C. Schlegel, "Synchronization requirements for multi-user ofdm on satellite mobile and two-path rayleigh fading channels," *Communications, IEEE Transactions on*, vol. 43, no. 234, pp. 887–895, 1995.
2. M. Tanno, Y. Kishiyama, N. Miki, K. Higuchi, and M. Sawahashi, "Evolved utra-physical layer overview," in *Signal Processing Advances in Wireless Communications, 2007. SPAWC 2007. IEEE 8th Workshop on*, pp. 1–8, IEEE, 2007.
3. J. Heiskala and J. Terry, "Ofdm wireless lans: a theoretical and practical guide," 2002.
4. C. Eklund, R. B. Marks, K. L. Stanwood, and S. Wang, "Ieee standard 802.16: a technical overview of the wirelessman/sup tm/air interface for broadband wireless access," *Communications Magazine, IEEE*, vol. 40, no. 6, pp. 98–107, 2002.
5. M. Morelli, C.-C. Kuo, and M.-O. Pun, "Synchronization techniques for orthogonal frequency division multiple access (ofdma): A tutorial review," *Proceedings of the IEEE*, vol. 95, no. 7, pp. 1394–1427, 2007.
6. I. W. Group *et al.*, *IEEE Standard for Local and Metropolitan Area Networks, Part 16: Air Interface for Fixed Broadband Wireless Access Systems*, 2004.
7. B. Roman, F. Stajano, I. Wassell, and D. Cottingham, "Multi-carrier burst contention (mcbc): Scalable medium access control for wireless networks," in *IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 1667–1672, 2008.
8. P. Wan, O. Frieder, X. Jia, F. Yao, X. Xu, and S. Tang, "Wireless link scheduling under physical interference model," in *IEEE INFOCOM*, pp. 838–845, 2011.
9. A. Dutta, D. Saha, D. Grunwald, and D. Sicker, "Smack: a smart acknowledgment scheme for broadcast messages in wireless networks," in *ACM SIGCOMM Computer Communication Review*, vol. 39, pp. 15–26, 2009.
10. K. Wu, H. Tan, Y. Liu, J. Zhang, Q. Zhang, and L. Ni, "Side channel: bits over interference," in *ACM MobiCom*, pp. 13–24, 2010.
11. K. Wu, H. Li, L. Wang, Y. Yi, Y. Liu, Q. Zhang, and L. Ni, "hjam: Attachment transmission in wlans," in *INFOCOM, 2012 Proceedings IEEE*, pp. 1449–1457, IEEE, 2012.
12. G. Zhou, C. Huang, T. Yan, T. He, J. A. Stankovic, and T. F. Abdelzaher, "Mmsn: Multi-frequency media access control for wireless sensor networks," in *IEEE Infocom*, pp. 1–13, 2006.

13. J. Zhao, H. Zheng, and G.-H. Yang, "Distributed coordination in dynamic spectrum allocation networks," in *New Frontiers in Dynamic Spectrum Access Networks, 2005. DySPAN 2005. 2005 First IEEE International Symposium on*, pp. 259–268, IEEE, 2005.
14. S. Sen, R. Choudhury, and S. Nelakuditi, "Listen (on the frequency domain) before you talk," in *ACM SIGCOMM Workshop on Hot Topics in Networks*, p. 16, 2010.
15. I. W. Group *et al.*, *IEEE 802.11n-2009: Enhancements for Higher Throughput*, 2009.
16. Y. Cheng, H. Li, P. Wan, and X. Wang, "Capacity region of a wireless mesh backhaul network over the csma/ca mac," in *INFOCOM, 2010 Proceedings IEEE*, pp. 1–5, IEEE, 2010.
17. B. Nardelli, J. Lee, K. Lee, Y. Yi, S. Chong, E. W. Knightly, and M. Chiang, "Experimental evaluation of optimal csma," in *INFOCOM, 2011 Proceedings IEEE*, pp. 1188–1196, IEEE, 2011.
18. Z. Zeng, Y. Gao, K. Tan, and P. Kumar, "Chain: Introducing minimum controlled coordination into random access mac," in *INFOCOM, 2011 Proceedings IEEE*, pp. 2669–2677, IEEE, 2011.
19. J. Proakis, *Digital Communications*. McGraw-Hill series in electrical and computer engineering, McGraw-Hill, 2001.
20. Y. Yang, Y. Liu, and L. Ni, "Level the buffer wall: Fair channel assignment in wireless sensor networks," *Computer Communications*, vol. 33, no. 12, pp. 1370–1379, 2010.
21. X. Feng, J. Zhang, and Q. Zhang, "Database-assisted multi-ap network on tv white spaces: Architecture, spectrum allocation and ap discovery," in *IEEE DySPAN*, pp. 265–276, 2011.
22. S. Wu, Y. Tseng, C. Lin, and J. Sheu, "A multi-channel mac protocol with power control for multi-hop mobile ad hoc networks," *The Computer Journal*, vol. 45, no. 1, pp. 101–110, 2002.
23. A. T. Garcia-Luna-Aceves and J. J. G. luna aceves, "Channel hopping multiple access with packet trains for ad hoc networks," in *In IEEE Mobile Multimedia Communications (MoMuC)*, 2000.
24. J. So and N. Vaidya, "Multi-channel mac for ad hoc networks: handling multi-channel hidden terminals using a single transceiver," in *ACM MobiHoc*, pp. 222–233, 2004.
25. J. Chen, S. Sheu, and C. Yang, "A new multichannel access protocol for ieee 802.11 ad hoc wireless lans," in *IEEE Proceedings on Personal, Indoor and Mobile Radio Communications*, vol. 3, pp. 2291–2296, 2003.
26. A. Tzamaloukas and J. Garcia-Luna-Aceves, "Channel-hopping multiple access," in *IEEE ICC*, vol. 1, pp. 415–419, 2000.
27. H. So, J. Walrand, and J. Mo, "Mcmac: A multi-channel mac proposal for ad-hoc wireless networks," in *IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 334–339, 2005.
28. P. Bahl, R. Chandra, and J. Dunagan, "Ssch: slotted seeded channel hopping for capacity improvement in ieee 802.11 ad-hoc wireless networks," in *ACM MobiHoc*, pp. 216–230, 2004.
29. C. Wong, R. Cheng, K. Lataief, and R. Murch, "Multiuser ofdm with adaptive subcarrier, bit, and power allocation," *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 10, pp. 1747–1758, 1999.
30. P. Mähönen and M. Petrova, "Minority game for cognitive radios: Cooperating without cooperation," *Physical Communication*, vol. 1, no. 2, pp. 94–102, 2008.
31. J. Park and M. Van Der Schaar, "Medium access control protocols with memory," *IEEE/ACM Transactions on Networking (TON)*, vol. 18, no. 6, pp. 1921–1934, 2010.
32. L. Cigler and B. Faltings, "Reaching correlated equilibria through multi-agent learning," in *The 10th International Conference on Autonomous Agents and Multiagent Systems*, vol. 2, pp. 509–516, 2011.
33. I. W. Group *et al.*, *IEEE 802.11-2007: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, 2007.
34. A. Acharya, A. Misra, and S. Bansal, "Design and analysis of a cooperative medium access scheme for wireless mesh networks," in *IEEE International Conference on Broadband Networks (BroadNets)*, pp. 621–631, 2004.
35. K. Mittal and E. Belding, "Rtss/ctss: Mitigation of exposed terminals in static 802.11-based mesh networks," in *IEEE Workshop on Wireless Mesh Networks (WiMesh)*, pp. 3–12, 2006.

36. M. Vutukuru, K. Jamieson, and H. Balakrishnan, “Harnessing exposed terminals in wireless networks,” in *Proceedings of the 5th USENIX Symposium on Networked Systems Design and Implementation*, pp. 59–72, 2008.
37. M. Jain, J. Choi, T. Kim, D. Bharadia, S. Seth, K. Srinivasan, P. Levis, S. Katti, and P. Sinha, “Practical, real-time, full duplex wireless,” in *ACM MobiCom*, pp. 301–312, 2011.

http://www.springer.com/978-3-319-04908-3

Attachment Transmission in Wireless Networks
Wang, L.; Wu, K.; Hamdi, M.
2014, XII, 63 p. 36 illus., Softcover
ISBN: 978-3-319-04908-3