MAC and PHY Proposal for 802.11af

Date: 2010-02-28

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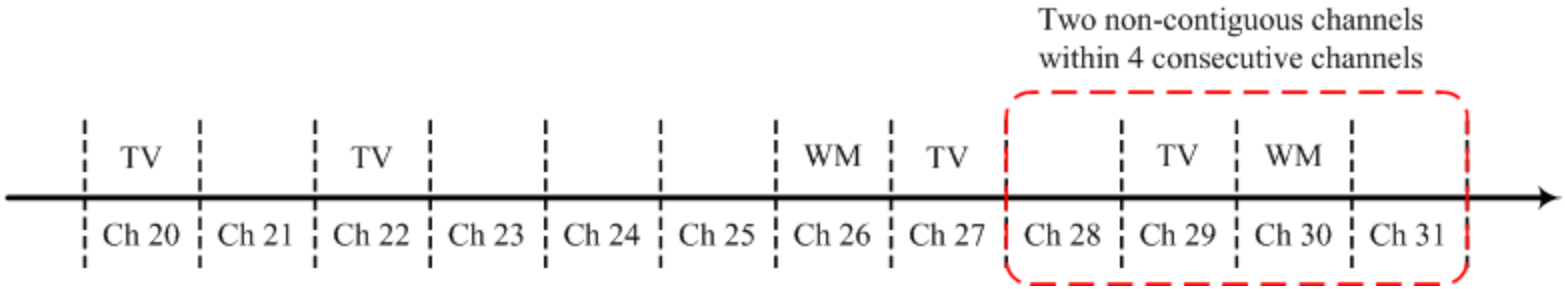
Outline

- **PHY Considerations**
- **MAC Considerations**
- **Conclusions**
- **References**

Characteristics of TV White Space (TVWS)

- **The spectrum opportunity of TVWS consists of fragments of different number of available TV channels.**
  - Variable channel bandwidth
- **The 802.11af should support the usage of multiple available channels in TVWS.**
  - Multiple contiguous available channels: 1, 2, 3, 4, (optional 8, 16)
  - Multiple non-contiguous available channels: within 4 consecutive channels
- **Use channel numbers specified by regulatory bodies**



Why Use Non-contiguous Channels?

- **Enjoy benefits of larger bandwidth, as in contiguous cases:**
  - Efficient – larger bandwidth results in higher data rate and a more efficient CSMA system.
  - Power saving – from information theory, for the same transmission power , larger bandwidth results in higher channel capacity.
- **Low additional complexity:**
  - Only one additional filter operation is needed if the multiple non-contiguous channels are within 4 consecutive channels.

OFDM PHYs in Current 802.11 Standards

- **OFDM with fixed subcarrier number (clause 17)**
  - 64 subcarriers for 5, 10 and 20 MHz channels.
- **OFDM with fixed subcarrier spacing (clause 20)**
  - 64 subcarriers for 20 MHz channel and
  - 128 subcarriers for 40 MHz channel
  - (256 subcarriers for 80 MHz channel in 802.11ac under consideration).
- **Abbreviations:**
  - FCN – OFDM with Fixed subCarrier Number
  - FCS – OFDM with Fixed subCarrier Spacing

Comparisons of FCN and FCS (1)

- **Chip design:**
  - FCN: Most of the current PHY design can be reused by adjustment of sampling frequency.
  - FCS: Preamble and pilot subcarrier allocation need to be redesigned when multiple channels are used.
- **Link initialization:**
  - FCN: A STA needs to try different bandwidth (RX filter) and sampling frequency to scan TV channels for operating APs
  - FCS: A STA can use the same bandwidth (RX filter) and sampling frequency for a single channel to demodulate control information provided that the control information is duplicated in each channel used.

Comparisons of FCN and FCS (2)

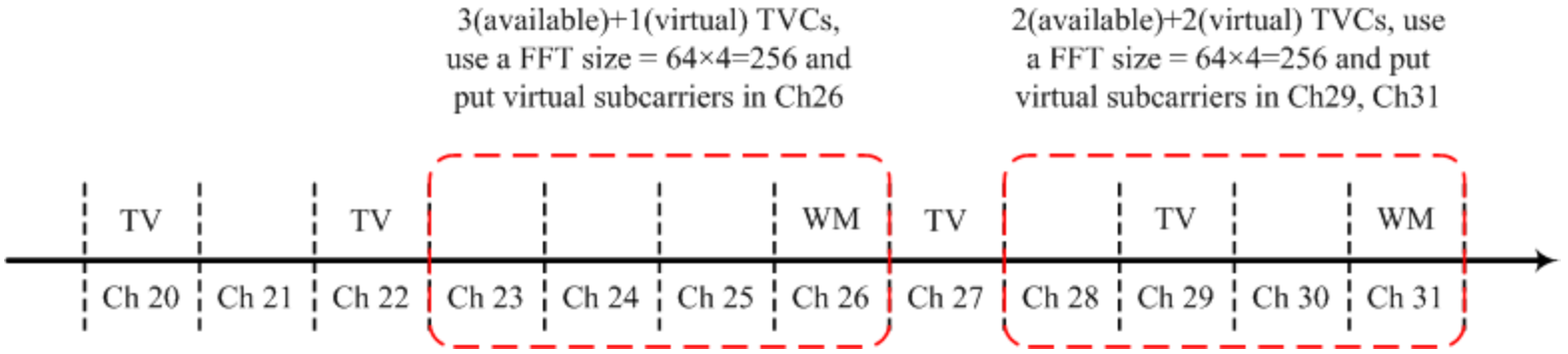
- **Slot time and IFS (inter-frame space):**
  - FCN: The length of an OFDM symbol is different for different bandwidth. IFSs need to be defined for different bandwidth.
    - When systems of different bandwidth coexist, what's the proper IFSs?
  - FCS: The length of an OFDM symbol is the same for different bandwidth. We need only one set of IFSs.
- **Multipath channel:**
  - From [4], for a service range of 0.5~2 km, the rms delay spread is 1 μs.
  - FCN: The CP length of using 64 subcarriers for 20 MHz is 0.8 μs.
    - Too short to handle multipath in long range services.
  - FCS: The CP length of using 64 subcarriers for each 6 MHz channel is 2.66 μs.

Comparisons of FCN and FCS (3)

- **Virtual carrier sense:**
  - FCN: STAs need to adjust sampling frequency and channel bandwidth (Rx filter) to receive NAV from other STAs.
  - FCS: All STAs can use the same sampling frequency and channel bandwidth to receive NAV from other STAs.
- **Coexistence: FCS provides a simpler way to facilitate coexistence of heterogeneous systems.**

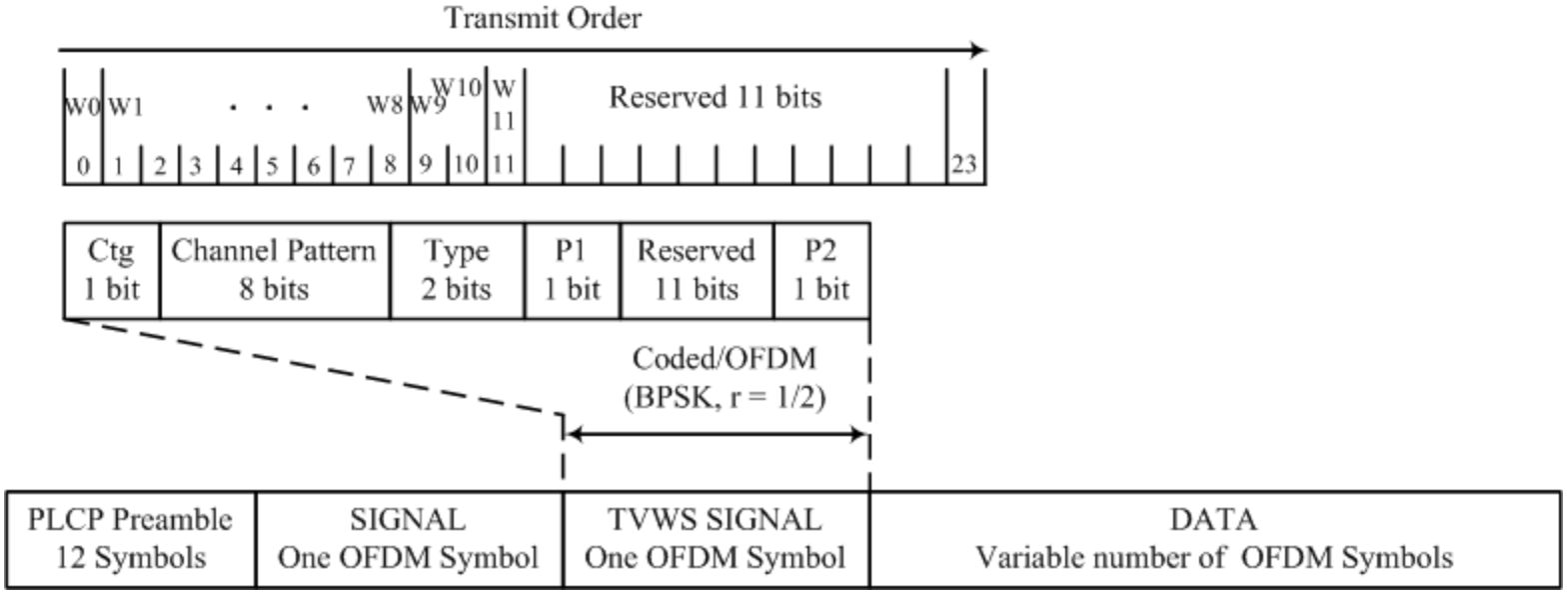
Proposed OFDM PHY

- **OFDM with fixed subcarrier spacing (FCS) is recommended.**
- **Each channel has 64 subcarriers.**
- **The possible FFT sizes are: FFT size (# of channels)**
  - Contiguous Channels: 64 (1), 128 (2), 256 (3,4), optional 512 (8) and optional 1024 (16)
  - Non-contiguous Channels: 256
  - Virtual subcarriers will be put in those channels which are not used.



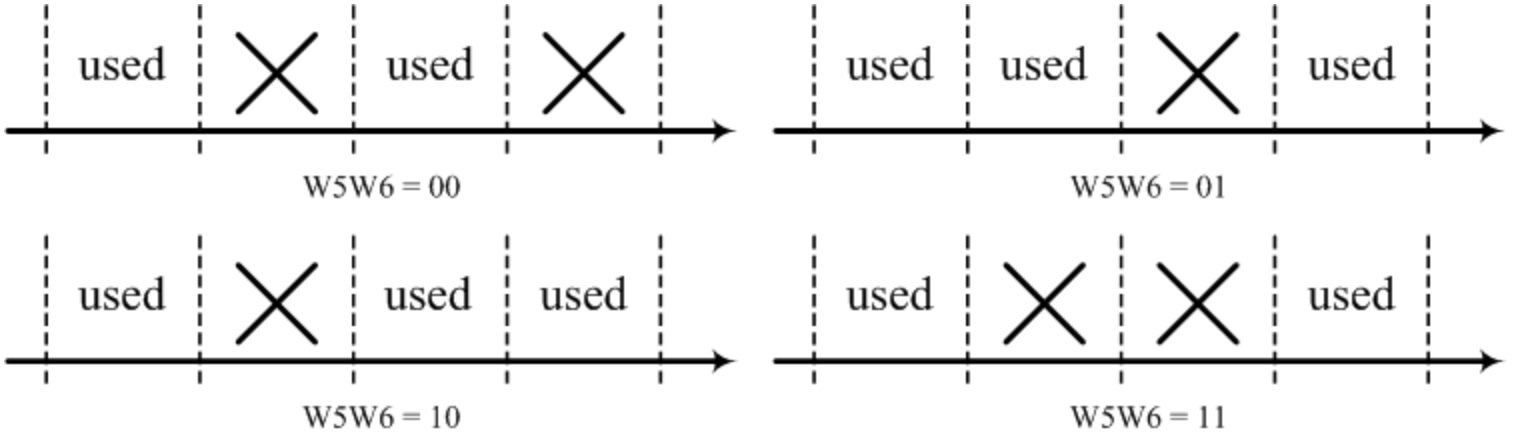
802.11af PPDU Frame Format

- **A TVWS SIGNAL OFDM symbol is added to carry TVWS parameters**
  - BSPK modulation, rate ½ CC, same as the SIGNAL SYMBOL in Clause 17.



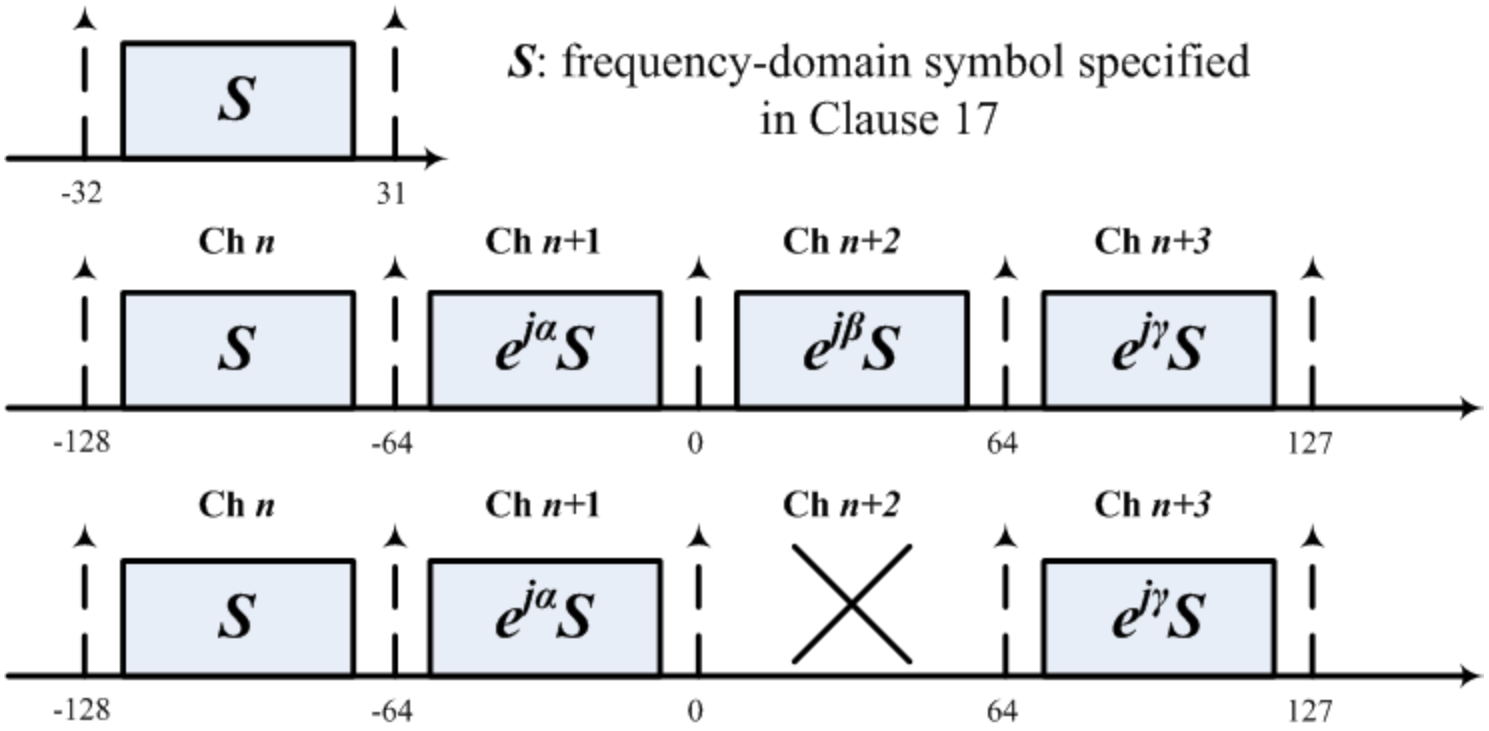
TVWS Parameters

- W0: contiguous (1) or non-contiguous (0) channels used.
- W1~W4: current channel number among used channels.
- W0=1, W5~W8: number of contiguous channels used.
- W0=0, W5W6: non-contiguous channel pattern, W7W8: reserved
- W9W10: regular frame (00), sensing frame (01), coexistence frame (10).
- W11W23: parity check bits.



PLCP Preamble and SIGNAL OFDM Symbols for Using Multiple Channels (1)

- **The PLCP preambles and two SIGNAL OFDM symbols have a duplicated structure in frequency domain**
  - similar to what are specified in Clause 20 for 40 MHz channel non-HT mode.



PLCP Preamble and SIGNAL OFDM Symbols for Using Multiple Channels (2)

- Let $S_{m,n}$, $-32 \le n \le 31$ denote the frequency domain symbol in the m^{th} channel.
- For STF, $S_{0,n}$ is the short training symbol specified in Clause 17.
- For LTF, $S_{0,n}$ is the long training symbol specified in Clause 17.
- For (TVWS) SIGNAL OFDM symbols, $S_{0,n}$ is generated by the same procedure specified in Clause 17 for SIGNAL OFDM symbols.
- The frequency-domain symbol in other channel is given by

$$S_{m,n} = S_{0,n} \times w(m)$$

  where $w = \{1, e^{j\alpha}, e^{j\beta}, e^{j\gamma}\}$ in the last slide.
- The function $w(m)$ is a sequence corresponding a phase rotation in channel m. The phase rotation sequence is designed to reduce PAPR. For example, from [3], $w = \{1, j, 1, -j\}$ gives low PAPR for up to using four contiguous channels.

Pilot Subcarriers for DATA OFDM Symbols

- **Contiguous channel cases:**
  - 1 Channel: use the one specified in Clause 17
    - 4 pilots: subcarrier index {-21,-7, 7, 21}
  - 2 Channels: use the one specified in Clause 20 for a 40 MHz (HT) transmission
    - 6 pilots: subcarrier index {-53,-25,-11,11,25,53}
  - More than 2 TVCs: need further investigation.
- **Non-contiguous channel cases:**
  - Use the one specified in Clause 17 for each single channel.
  - The virtual subcarrier in the middle can be replaced by a data subcarrier since it is no longer the DC position.
  - For two contiguous channels , use the one specified in Clause 20 for a 40 MHz (HT) transmission.

MAC Consideration

- **Extend the EDCA mechanism in HCF to facilitate coexistence between 802.11 and non-802.11 systems.**
  - Non-802.11 devices need to embed DCF function.
  - An over-the-air coexistence mechanism.
- **Extend the function of quiet interval in DFS for coexistence.**
  - Non-802.11 devices do not need the extra DCF function.
  - An backhaul connection coexistence mechanism.

Access Categories for non-802.11af Devices

Class	Coex
AIFSN	TBD
CWmin	TBD
CWmax	TBD
TXOPLimit(ms)	TBD

- **Non-802.11 devices employ DCF to compete for medium and hence, they need to receive control and management frames from 802.11 STAs.**
- **An TXOP is granted for each successful medium contention.**
- **A distributed over-the-air coexistence mechanism.**

Coexistence Intervals

- **The quiet interval scheduling function specified for Dynamic Frequency Selection (DFS) can be extended for coexistence.**
  - Add coexistence element with same parameters as those in quiet element
- **Assume that non-802.11 devices can make a coexistence request to 802.11 devices through a backhaul coexistence manager (assume it exists) and vice versa.**
- **802.11 devices schedule coexistence intervals for non-802.11 devices using the coexistence interval scheduling function.**
- **Non-802.11 devices do not need any extra functionality.**
- **A backhaul connection coexistence mechanism.**

Conclusions

- **OFDM with fixed subcarrier spacing is proposed to simplify PHY and MAC design.**
- **DCF and EDCA mechanisms are extended to realize distributed coexistence of heterogeneous systems.**
- **The quiet interval scheduling can be extended to facilitate coexistence of heterogeneous systems.**

References

1. IEEE Standard, "IEEE Standard for Information Technology-Telecommunications and Information Exchange Between Systems-Local and Metropolitan Area Networks-Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," IEEE, New York, NY, June 2007.
2. FCC, Second Report and Order and Memorandum Opinion and Order, ET Docket No. 08-260, November 2008.
3. L. Lanante *et al*., "IEEE802.11ac Preamble with Legacy 802.11a/n Backward Compatibility," doc.:IEEE 802.11-09/0847r1.
4. M. Rahman et al., " Channel Model Considerations for P802.11af, " doc.:IEEE 802.11-10-0154-01-00af.

Thanks for your attention !

Appendix

A Spectrum Usage Example