IEEE 802.11ba: Low-Power Wake-Up Radio for Green IoT

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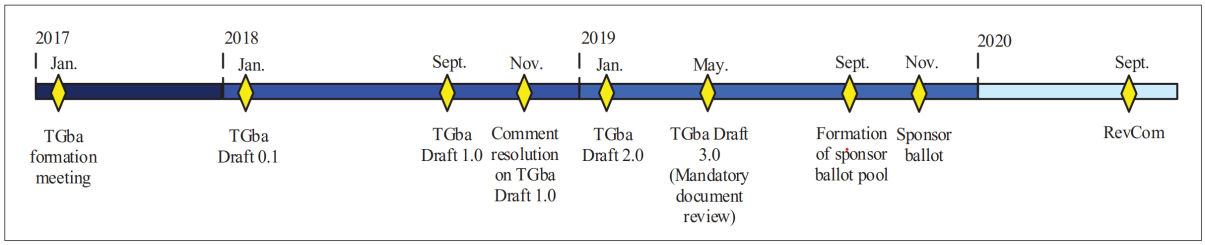
tags: `Paper Study`

Introduction

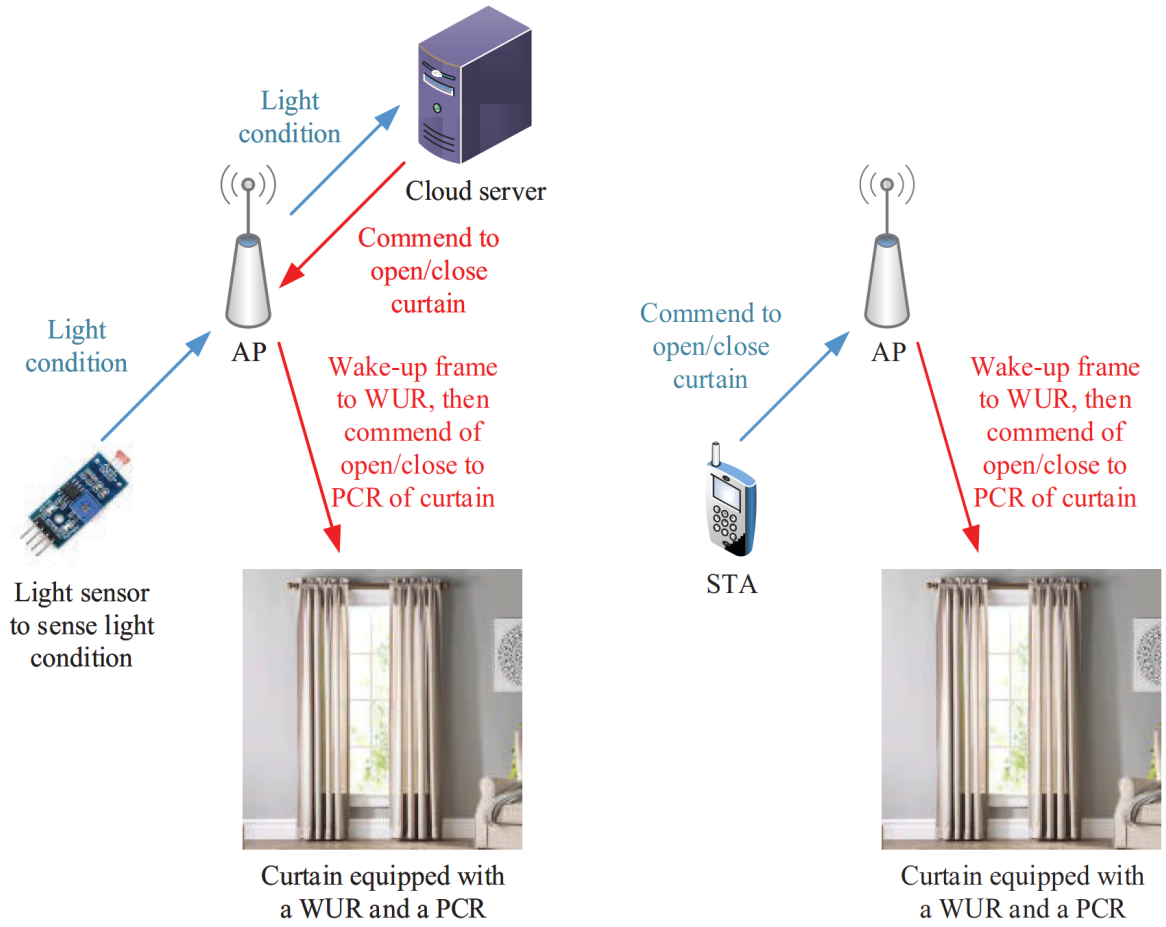
- Green IoT:
  - Battery life
  - low power consumption
  - most efficient way for power saving: goto sleep state.
  - Wake-up device from AP when in sleep state.
  - penalty: longer data reception time
- WUR standard development timeline
  - 2017 draft 0.1
  - 2019 Draft 2.0(?)



- Target goal: < 1mW in WUR mode
- Two Radio in Wi-Fi:
  - PCR: primary connectivity radio
  - WUR: companion connectivity radio
- Introduce new Wake-up Frame
  - STA received a wakeup frame, will turn PCR into active mode.
  - WUR in the same band as legacy/n/ac/… Wi-Fi

Deployment Scenarios

- Smart home example: smart curtain(窗簾)



Use Case 1 **Use Case 2**

- Curtain controller is in sleep mode
- light sensor senses strong light => trigger server => server control curtain
  - AP wake-up curtain controller, and exchange control data package.

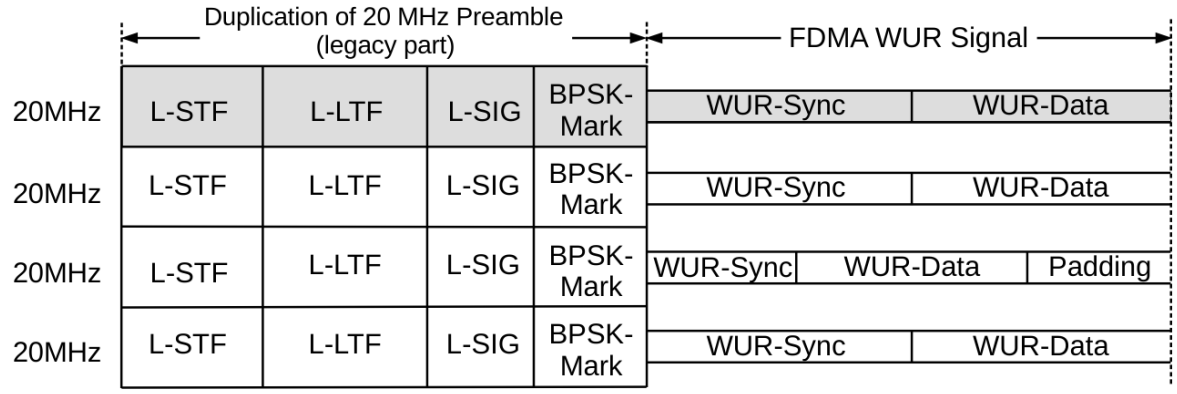
PHY

Waveform and modulation of WUR

- 4MHz BW (13 subcarriers in 312.5KHz subcarrier spacing)
- not carry any data information (only sync and mac control frames)
- modulated by AP using OFDM system (only use 13 subcarrier of whole NFFT=64)
- information is modulated in OOK per subcarrier, aka MC-OOK
  - non-coherent receiving(such envelope detector) is possible => no need high accuracy SX/xtal/PLL.

PLCP and WUR Frame format

- Frame format
  - Example of BW80



- Follow legacy non-ht preamble and two extra bpsk makrer
- non-ht preamble for silencing legacy devices to prevent collision.
- BPSK markers to prevent impairment due to significant power jump from full-band width to 4MHz
- maximum WUR frame upto 5.6ms.

Data field

- Two data rate : 62.5Kbps and 250Kbps.
  - 250Kbps for indoor application in 70/105 m of 5G/2.4G
  - 62.5Kbps for outdoor wide range application.

SYNC Field

- using lowest rate
- SYNC1(128us) for 62.5Kbps packet
- SYNC2(64us) for 250Kbps packet

MAC

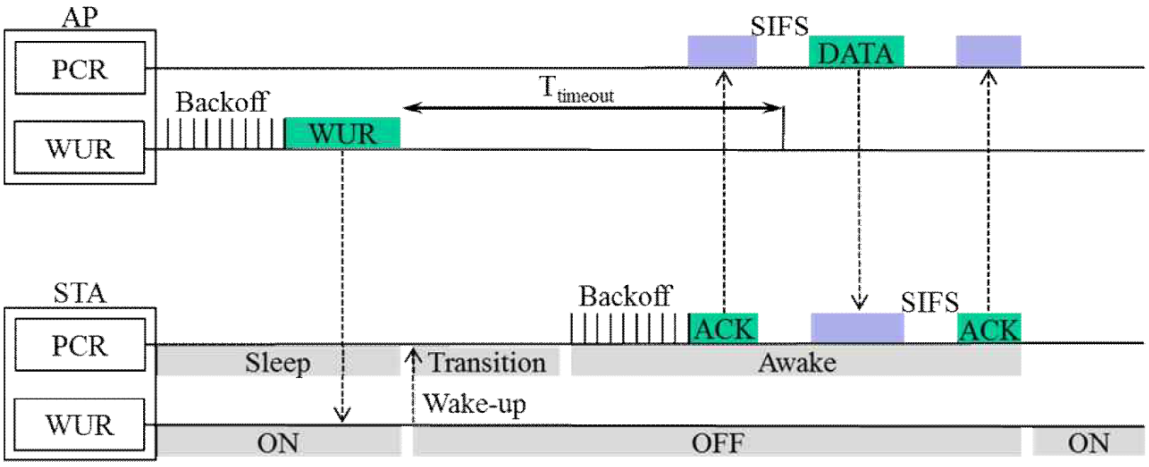
Basic Wake-up operations

- WUR only able to signaling Wakeup procedure no ability to carrier data.
- WUR response using PCR
- Wakeup delay:
  - mainly due to STA completely turn-off, need extra time for wakeup procedure
  - longer than Wi-Fi typical response time.
  - Slow wake-up response make slow error recovery of AP
    - AP needs more time to check if retransmission of the wake-up signaling.
    - impact data delivery latency, but latency is not critical in low power IoT device.

WUR Duty cycle

- Exchange wake-up duty information field before into WUR mode
- Duty parameters

    - period
    - start point of ‘on’ duration
    - length of ‘on’ duration
    - minimum wake-up duration:
        - AP should advertise minimum wake-up duration
        - minimum wake-up ‘on’ period.
- Time parameters
    - basic time unit in 4us
    - 16bits ‘on’ period => 4×2^{16}us duration
    - 16bits number of dutys => total 2^{34}us duty
- Procedures
    - Ap send Wake-up signal in WUR ‘on’ Period.
    - if WUR ‘on’ duty low, will cause longer wake-up procedure.



WUR Mode

- PCR:
    - can be shutoff before STA receives any WUR frame.
    - active after STA receives WUR frame
        - first send response when receive WUR frame
- Four type WUR frame:
    - WUR Wake-up
    - WUR Beacon
    - WUR discovery
    - WUR vendor-specific
- When into WUR mode
    - device not to sync with beacon frame and
    - any negotiated service period is suspended.
- GoTo WUR Mode
    1. Negotiation WUR parameters.
    2. STA send WUR Mode Setup Action Frame.
    3. AP reply ack of WUR Mode Setup Action Frame
    4. doze mode and shutoff PCR

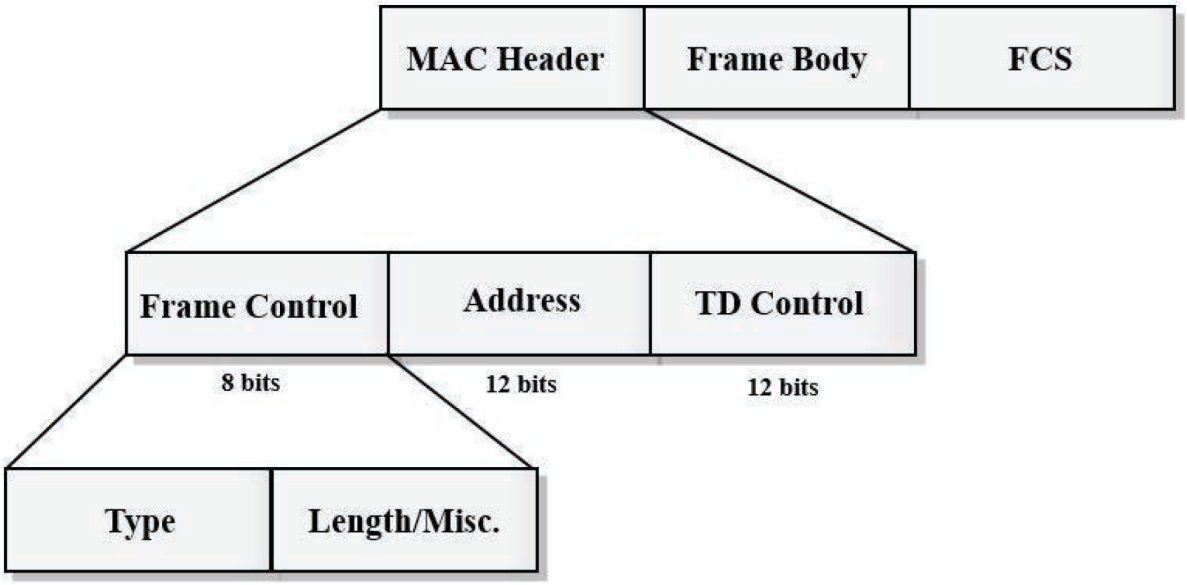
- STA self wake-up:
  - send a WUR Mode Tear-down Action frame to AP.
- WUR mode suspend:
  - keep WUR parameter, but STA exists WUR mode.

Channel Access

- WUR frame is in control frame, will be higher priority AC(access categories)
- AP not update contention window when sending WUR signal to STA due to slow response of STA in WUR mode.

Protocol Data Unit

- WUR Frame: Header, frame body, frame check(CRC)



- Header:
  - frame control
    - type: which type of WUR frame
    - length/misc: others info.
  - address
    - as WID: the Wakeup id of WUR device
    - as GID: the group id of the grouped WUR devices.
    - if Beacon WUR: transmit id
  - TD Control
    - WUR Beacon, a partial TSF for the purpose of sync.
    - WUR frames, other types of enhancements