Outline

• 802.11a Overview
• Medium Access Control Design
• Baseband Transmitter Design
• Baseband Receiver Design
• Chip Details
What is 802.11a?

- IEEE standard approved in September, 1999
- 12 20MHz channels at 5.15 - 5.35 GHz and 5.725 - 5.825 GHz
- Coded OFDM with 48 data and 4 pilot subcarriers. Coding rate = \{1/2, 2/3, 3/4\}. Modulation = \{bpsk, qpsk, 16qam, 64qam\}
- Data rate: 6Mb/s - 54Mb/s per channel
- Symbol Format:

```
<table>
<thead>
<tr>
<th>10 short symbols</th>
<th>2 long symbols</th>
<th>rate/length</th>
<th>data symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>8us</td>
<td>8us</td>
<td>4us</td>
<td>n*4us</td>
</tr>
</tbody>
</table>

- signal detect, agc, freq. est., timing est.
- channel est., freq. est.
```
Why 802.11a?

Compared to 802.11b:

• higher data rate per channel (peak of 54Mb/s vs. 11Mb/s)

• measured throughput is 2 to 5 times higher in a typical office environment

• more non-overlapping channels (12 vs. 3) implies less co-channel interference

• the result is ~10x higher system capacity, accommodating more users or enabling lower deployment costs

• 5GHz bands have less interference (2.4GHz has 802.11b, HomeRF, Bluetooth, cordless phones, microwave ovens ...)

• less energy per bit transferred
System Overview

* D. Su, et al., ISSCC 2002, Paper 5.4
MAC Partitioning

Partitioning is based on required timing.

Timing-critical functions:

- demand fast response or precise timing. Managed by the PCU.
- include CRC generation and checking, hardware-level frame retry, channel access, timer updates, and generation of special frames such as beacons, ACK, CTS

Non-timing-critical functions:

- performed in the driver software executing on the host
- include complex frame exchanges (e.g.: authentication and association), fragmentation, frame buffering and bridging, and other network management functions
Baseband Transmitter

- scrambler
- encode
- puncture
- tx data from MAC
- stall to MAC
- interleave
- map
- scale
- pilots, long training
- short training
- ifft
- upsample
- fir
- differential I and Q to analog front end
- dac
Baseband Receiver

differential I and Q from analog front end

adc

donsample fir

remove dc offset

rotate
to fft

differential I and Q from analog front end

rx gain to analog front end

signal detect and agc

fir

corelate

symbol timing

pipeline control

rx gain to analog front end
Baseband Receiver (cont)

fft → channel correct → de-interleave → viterbi decoder

channel estimate and tracking

pipeline control

from rotator

rx data to mac
Signal Detection and Automatic Gain Control

• need to detect ~60dB range of received signal strength

• may require multiple power measurements and gain changes within ~4us

• for weak signal detection, auto-correlated power is measured with a period of 0.8us (short symbol duration)

• for strong signal detection, raw power is measured, especially saturation at the ADC

• the goal is to maximize signal size at the ADC while providing headroom for adjacent channel interference and the peak-to-average-ratio of OFDM symbols
AGC Loop

antenna switch

switch control

4 GHz mixer

RF gain

IF gain

1 GHz mixer

baseband gains

adc

fir

auto correlate

measure power

digital chip

analog chip

external component
Fast Fourier Transform

128-pt FFT reduces adjacent channel filtering requirements and preserves the guard interval.

- Time-multiplexed radix 4/2 butterfly datapath
- Contains memory for input, temporary storage and output
- Shares hardware with the IFFT

\[ M = \text{single-ported memory} \]
FFT RX Butterfly Diagram

Frequency-domain outputs
Pilot Tracking and Channel Correction

- From FFT
- Pilots
- Long1 training
- Long2 training
- Data

- Symbol timing adjust
- Angle adjust
- Training symbol pilots
- Magnitude adjust

- Pilot tracking core
- FIR
- Complex inverse
- Pilot magnitude multiply
- Rotate

- Composite channel correction
- Channel correction multiply

- To de-int
Pilot Phase Tracking

- for each data symbol, for each of the 4 pilots, track total change in phase compared to the training symbols
- perform a least squares fit to determine phase correction for each data subcarrier
Pilot Tracking (cont)

- adjust channel estimates to account for frequency estimation error, phase noise and symbol timing drift
- drift in offset indicates frequency estimation error. Apply to rotator before FFT to reduce inter-carrier interference
- drift in slope indicates a shift in symbol timing. As slope becomes steeper, adjust symbol timing later. As slope becomes flatter, adjust symbol timing earlier
- pilot magnitude tracking monitors amplitude variations by comparing pilot power in the training symbols to pilot power in the data symbols
Viterbi Decoder

- branch metric unit computes soft trellis weights from the decoded constellations
- add-compare-select (ACS) array is radix-4, fully parallel

traceback memory partitioned into three rotating buffers

64 states
Power Management

Sleep:

- the chip can be programmed to sleep automatically and awake just before the next beacon

- the PCU parses the beacon to determine whether to remain awake for additional frames or re-enter sleep. Host interaction is required only if additional frames are to be processed.

Design Optimization:

- streamlined design, especially for datapaths
- MAC implemented with dedicated logic (yet still highly flexible), requiring no off-chip RAM or program storage
- aggressive clock gating
# Chip Details

<table>
<thead>
<tr>
<th>Technology</th>
<th>Standard 0.25u CMOS, 5 layer metal, 2.5V core, 3.3V I/O 4.0M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transistor Count</td>
<td>4.0M</td>
</tr>
<tr>
<td>Die Size</td>
<td>6.8 mm x 6.8 mm</td>
</tr>
<tr>
<td>Package</td>
<td>196-pin BGA</td>
</tr>
</tbody>
</table>

## Power at 54Mb/s (Tx/Rx)

<table>
<thead>
<tr>
<th>Component</th>
<th>Tx</th>
<th>Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>219</td>
<td>203 mW</td>
</tr>
<tr>
<td>DACs + supporting circuitry</td>
<td>68</td>
<td>0 mW</td>
</tr>
<tr>
<td>ADCs + supporting circuitry</td>
<td>0</td>
<td>211 mW</td>
</tr>
<tr>
<td>I/O</td>
<td>25</td>
<td>24 mW</td>
</tr>
<tr>
<td>PLL</td>
<td>14</td>
<td>14 mW</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>326</td>
<td>452 mW</td>
</tr>
</tbody>
</table>
Die Photograph