EECS 373
Design of Microprocessor-Based Systems

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Lecture 12: Wireless Communication
October 14, 2010

Minute Quiz...

Announcements

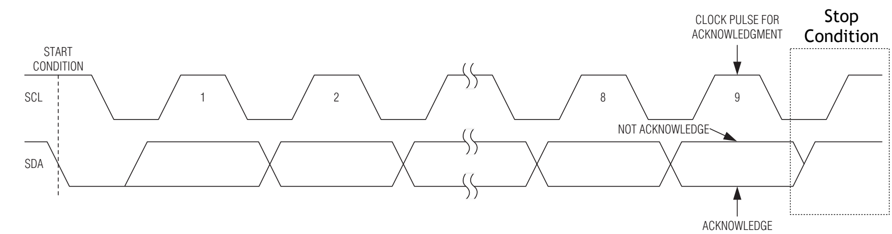
- How do we deal with virtual timers that are close together?
  - Keep time running while executing current handler
  - When handler returns, check for time and the next virtual timer
  - If it is time, execute the next handler. Else, set the HW timer

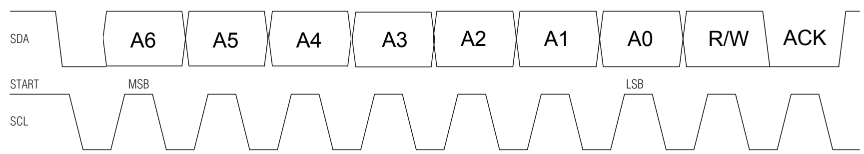
Inter-Integrated Circuit - I^2C

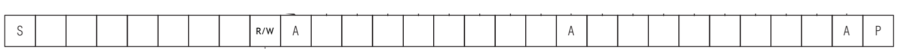
- What is the simplest way to connect many serial devices with just 2 wires?
- Addressing of chips
- Message acknowledgment
- Single master - multiple slave
- Multiple master - multiple slave

- Two bi-directional open-drain lines SDA, SCL
  - Pull-up resistors to Vcc
- 7-bit address space with 16 addresses reserved

I2C



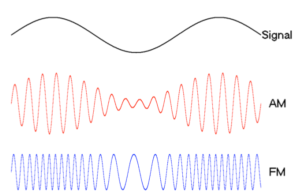




How can we cut the cord?

Modulation is Key to Wireless Communication

- Transmit *information* over an analog pass-band channel
- AM/FM Modulation

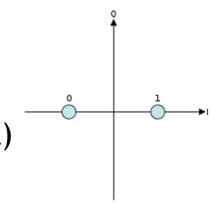


- Alphabet of $M=2^N$ alternative symbols, each of size N
- If we have f_s S/s, the data rate is $N \cdot f_s$ bits/s
- Fundamental Digital Modulation
  - Phase-Shift Keying (PSK)
  - Frequency-Shift Keying (FSK)
  - Amplitude-Shift Keying (ASK)
  - Quadrature Amplitude Modulation (QAM)

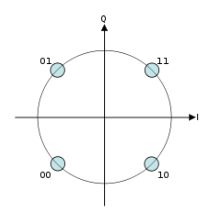
Phase Shift Keying

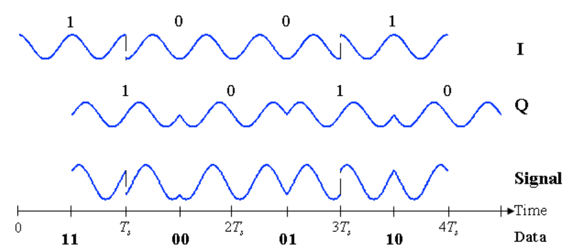
- Binary PSK (BPSK) M=2
- Quadrature PSK (QPSK) M=4
- 8PSK (M=8), 16PSK (M=16)
- Differential PSK (DPSK) Differential QPSK (DQPSK)
- Offset QPSK (OQPSK)

BPSK Constellation



O-QPSK Constellation



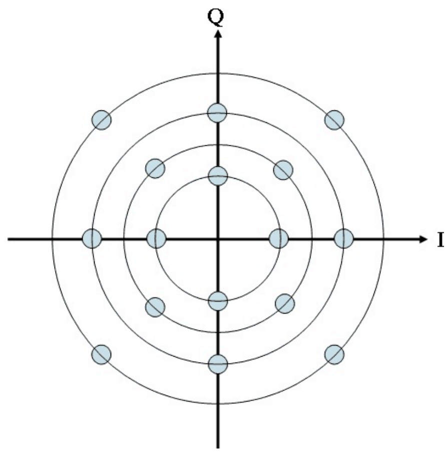


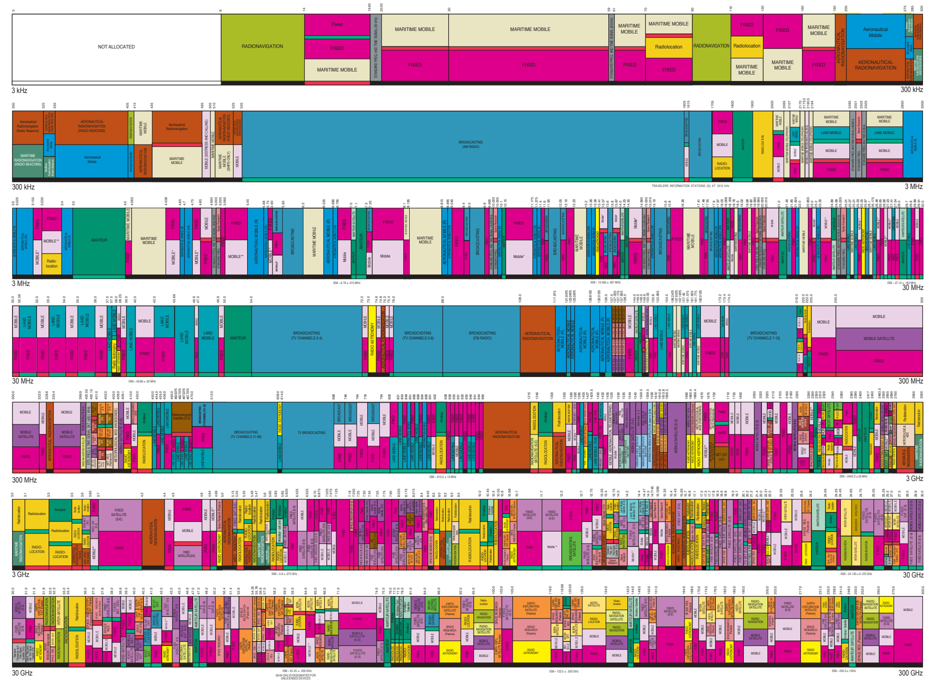
Figures from wikipedia.org

Quadrature Amplitude Modulation

- Adds amplitude modulation to phase shift keying

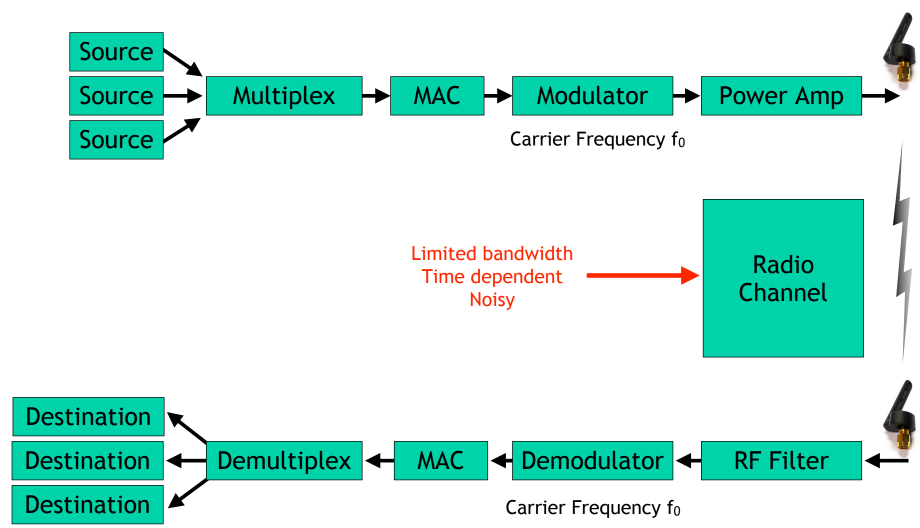
16-QAM Constellation





Why should you care about
Wireless Embedded Systems?

Digital Radio



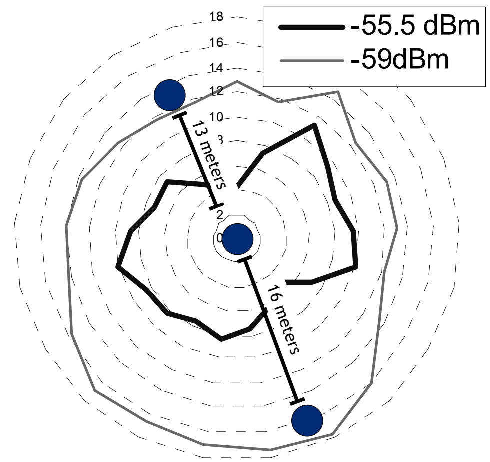
Radio Channel

- Path loss proportional to $1/d^n$
- Typical path loss constants

Environment	n
Free Space	2
Urban area cellular radio	2.7-3.5
Shadowed urban cellular radio	3 - 5
In-building Line of Sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

- Problems
  - Channel is time-varying and can be significantly different for nodes at the same distance
  - Link can even be asymmetric, i.e., the link between node 1 and 2 is different than the one from node 2 to 1

No Disk Model Connectivity

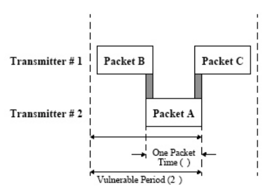


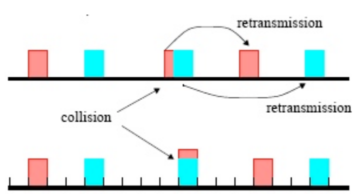
- Hidden Terminal Problem

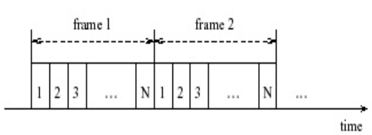
Zhou et al, ***Impact of Radio Irregularity on Wireless Sensor Networks***

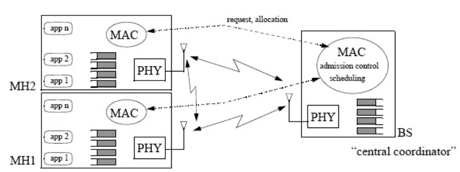
Taxonomy of MAC Protocols

- Random-access vs. Scheduled
- Time Slotted vs. Non-slotted
- Peer-to-peer vs. Master-slave
- MAC level retransmission









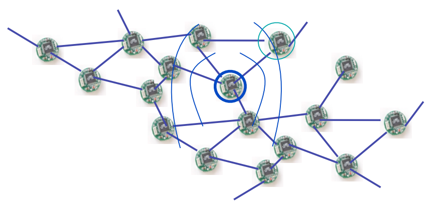
Adapted from M. Srivastava EE202B Lecture

Some Common Examples

- ALOHA
  - Random, slot-less or slotted, peer-to-peer
- IEEE 802.11 infrastructure DCF and ad-hoc mode
  - Carrier Sense Multiple Access With Collision Avoidance (CSMA/CA)
  - Random, slot-less, peer-to-peer
- IEEE 802.11 infrastructure PCF
  - Scheduled (polling), slot-less, master
- Bluetooth Piconets
  - Scheduled (polling), time-slot (with frequency hopping), master
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

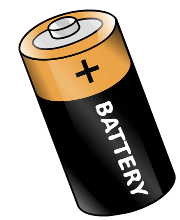
Multi-Hop Routing

- Different protocols and algorithms for different goals
- Any-to-any routing
  - DSDV, DSR, AODV
- Geographic Routing
  - Nodes know their own and their neighbor location
  - Address is physical location of node
  - Forward to neighbor closest to address
- Directed Diffusion
  - Data, not node, centric
  - Nodes publish data, users subscribe
- Flooding, Gossiping, Trickle
- Collection
- IPv6 LoWPAN RPL ('ripple')
  - proactive distance vector approach
  - optimized for low-power networks



Ack: Culler, MobiHoc '05

Power Aware MAC Protocols



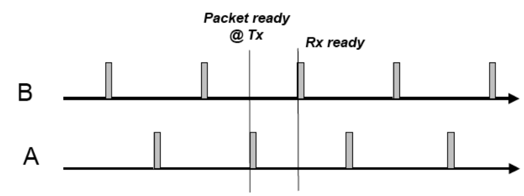
TI CC2520, TI MSP430, Actel SmartFusion Power Comparison

- TI CC2520
  - RX 18.5mA
  - TX 33.6 mA @ +5 dBm, 25.8 mA @ 0 dBm
  - < 1 uA in power down

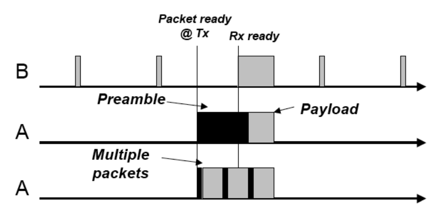
- TI MSP430F5437A
  - Active Mode: 5.7 mA, 3.0 V @ 25 MHz
  - Standby Mode: 2.1 uA, 3.0 V

- Actel SmartFusion
  - MSS running at 100 MHz, 40 mA
  - MSS in WFI at 100 MHz, 20 mA
  - Stand By: 3 mA on 1.5 V, 1 mA on 3.3 V
  - Time Keeping: 10 uA on 3.3 V

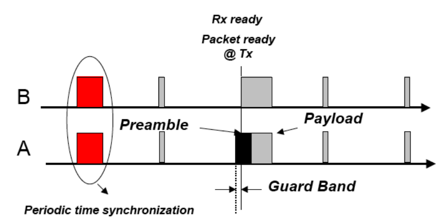
Time is Energy



Time Uncertainty Problem



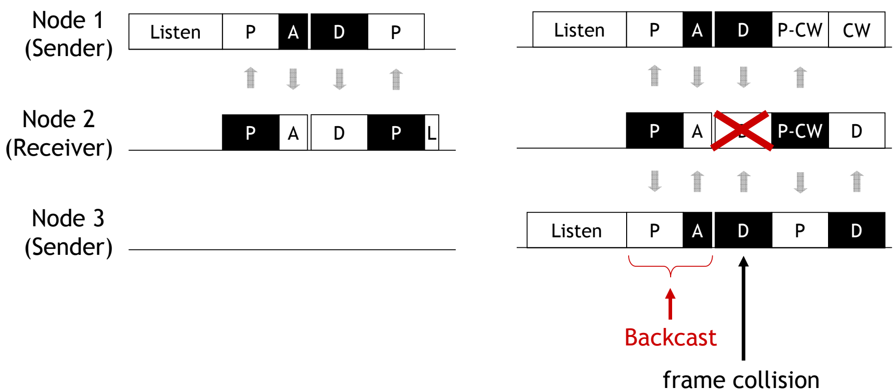
Asynchronous Approach
(long preambles: e.g. 1212B @ 2.2%)



Synchronous Approach
(frequent sync packets: e.g. every 15s)

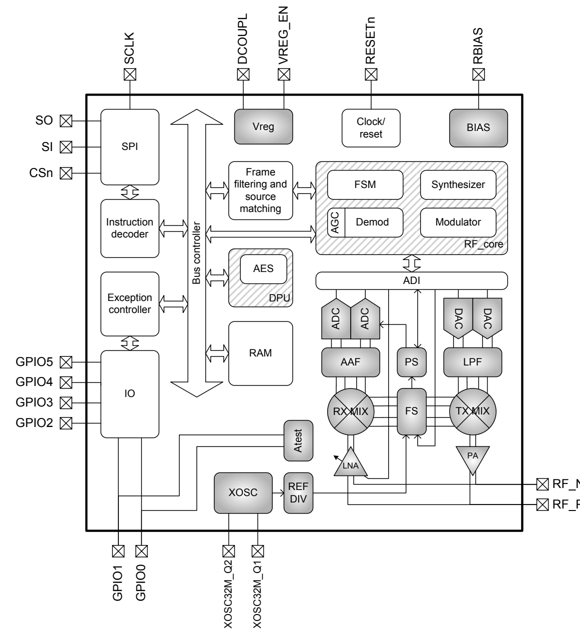
Adapted from M. Srivastava EE202B Lecture

Receiver Initiated MACs



from P. Dutta et. al "Design and Evaluation of a Versatile and Efficient Receiver-Initiated Link Layer for Low-Power Wireless"

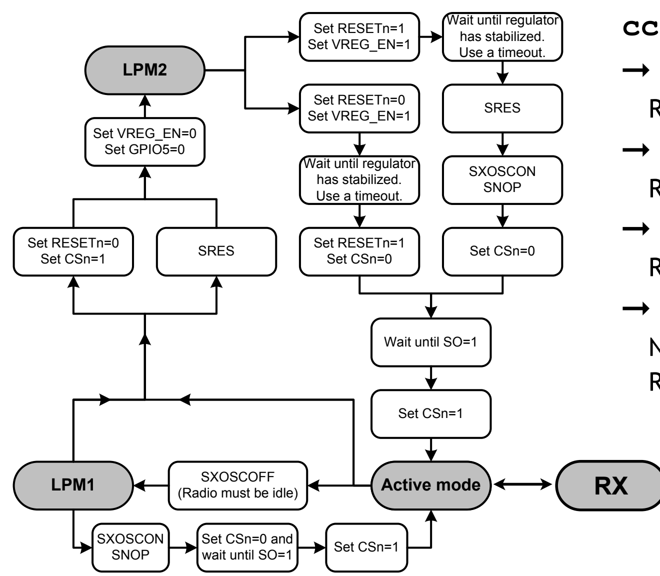
Talking to a Radio, TI CC2520



TI CC2520 GPIO Configuration

GPIO pin	Dir	Value	Pull up	Extra drive	Polarity	Signal	GPIOCTRLn value (hex)	Description
0	Out	0	No	No	Positive	clock	0x00	1MHz clock signal with 50/50 duty cycle.
1	Out	0	No	No	Positive	fifo	0x27	High when one or more bytes are in the RX FIFO. Low during RX FIFO overflow.
2	Out	0	No	No	Positive	fifop	0x28	High when the number of bytes in the RX FIFO exceeds the programmable threshold or at least one complete frame is in the RX FIFO. Also high during RX FIFO overflow.
3	Out	0	No	No	Positive	cca	0x29	Clear channel assessment. See FSMSTAT1 register for details on how to configure the behavior of this signal.
4	Out	0	No	No	Positive	sfd	0x2A	Pin is high when SFD has been received or transmitted. Cleared when leaving RX/TX respectively.
5	In	Tie to ground or VDD	No	No	Positive		0x90	No function

TI CC2520 Power States



cc2520driver.h

→ RX
RadioState_turnOn()

→ Active
RadioState_standby()

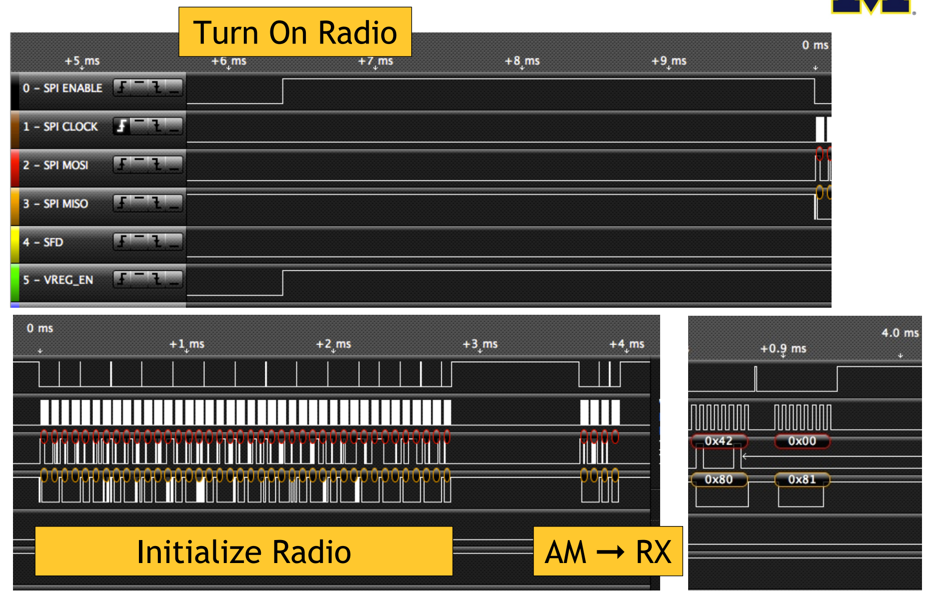
→ LPM1
RadioState_turnOff()

→ LPM2
Not implemented yet
RadioState_shutdown()

TI CC2520 Power States (2)

- Switching state is NOT instantaneous
- Depends on
  - Radio hardware switch on/off times (e.g. crystal bootup)
  - SPI communication speed for initial configuration after shutdown
- Power Draw
  - RX: 18.5mA
  - TX: 33.6 mA @ +5 dBm
  - Active Mode: 1.6 mA
  - LPM1: 175 uA
  - LPM2: 30 nA
- Wake-Up and Timing
  - LPM2 → Active Mode: 0.3 ms (regulator + XOSC startup time)
  - LPM1 → Active Mode: 0.2 ms (XOSC startup time)
  - AM → RX or TX: 192 us
  - DOES NOT INCLUDE SPI TRANSFERS!

TI 2520 Driver Bootup



Mostly driver limitations, and slow SPI Clock @ 160kHz

TI CC2520 Extra Features

- Received Signal Strength RSSI
  - 8-bit signed
  - Calculated for every packet received

```
void Radio_receive(uint8_t seqn, uint16_t panid, uint16_t saddr,
uint16_t daddr, uint8_t* payload, uint8_t length, int8_t rssi);
```

  - Approximately related to received signal power as
    P = RSSI - OFFSET [dBm]
    where OFFSET ≈ 76 dBm
- CCA
  - Clear channel assessment
  - Measures noise level of RF channel
  - High noise level indicates on-going communication
  - Implemented, but not exported in current driver
- Many many more features
  - See TI CC2520 Datasheet
    http://focus.ti.com/lit/ds/symlink/cc2520.pdf

Radio Modules

- IEEE 802.15.4 Radios
  - X-Bee
    - Out-of-the-box RF communication
    - Serial UART interface (API or AT Commands)
  - Atmel AT86RF230
  - STM32W (Cortex-M3 & Radio on a chip)
- ANT
  - e.g. Nordic nRF24AP1 or nRF24AP2
  - Nike+ and in many iPhones/iPods
- WiFi
  - DigiConnect ME WiFi
- Cellular
  - Telit GM862, GSM/GPRS & GPS
  - Runs Python Scripts
- RFID, DASH7, Bluetooth, Z-wave, RuBee, NFC



Some References

- Prabal Dutta, Stephen Dawson-Haggerty, Yin Chen, Chieh-Jan Mike Liang, and Andreas Terzis, "Design and Evaluation of a Versatile and Efficient Receiver-Initiated Link Layer for Low-Power Wireless," ACM Sensys 2010 (http://www.eecs.umich.edu/~prabal/teaching/eecs373-f10/readings/p101-dutta.pdf)
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- Gahng-Seop Ahn, Emiliano Miluzzo, Andrew T. Campbell, Se Gi Hong, Francesca Cuomo, "Funneling-MAC: A Localized, Sink-Oriented MAC for Boosting Fidelity in Sensor Networks," ACM Sensys 2006.
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