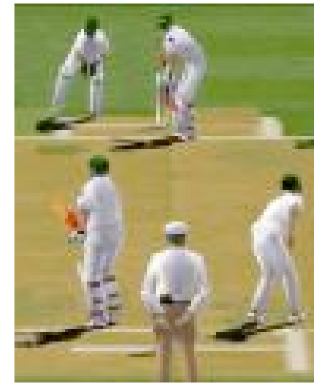


Crickets

Tutorial on using cricket location system

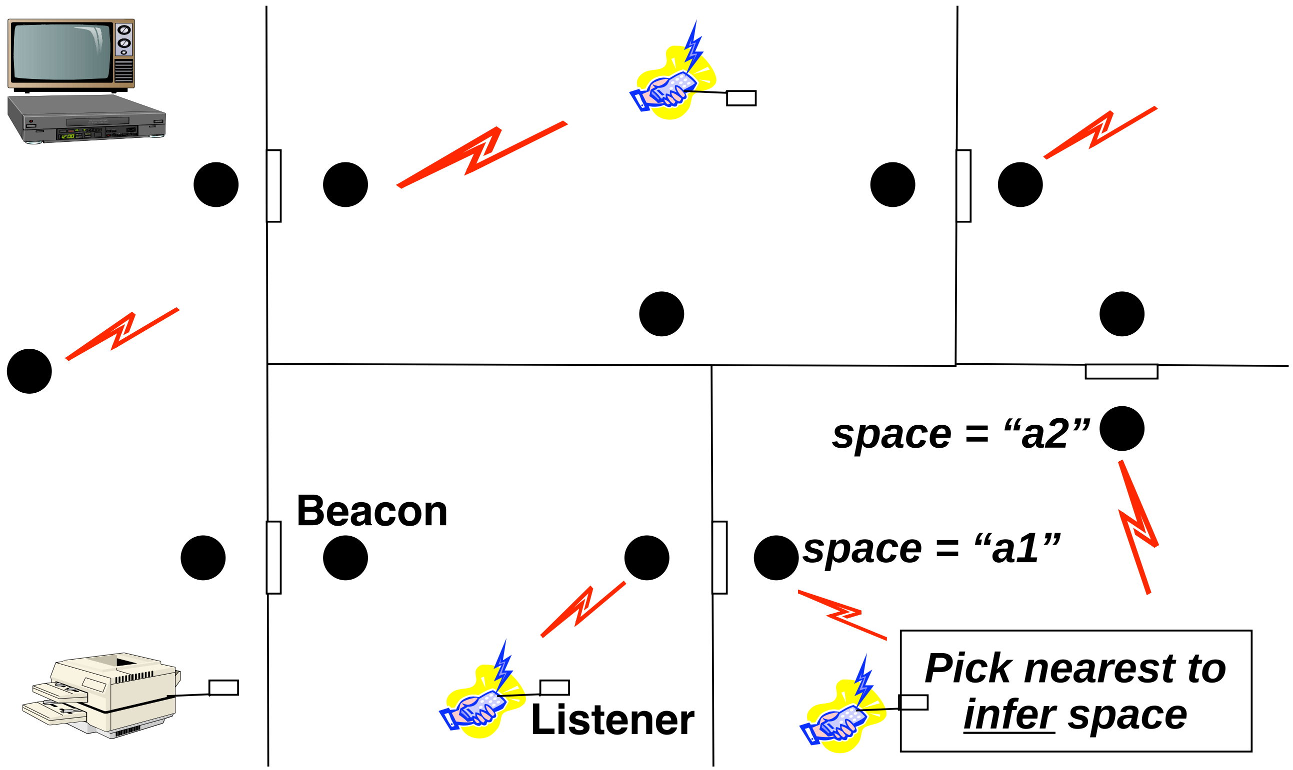
Cricket Goals

- Research prototype
  - build and then evaluate
- Useful mainly indoor environments
  - walls, ceilings not too far
- Recognize spaces, not just physical position
  - good boundary detection is important
    - doors, floors, etc.
- Preserve user's privacy
  - Big-brother can be a bother
    - user has choice to reveal location

Features

- Distributed architecture
  - No wired infrastructure
  - Easy deployment (no satellites)
  - Low maintenance
- Users are not tracked
  - Listeners are passive
  - Large number of listeners w/o interference
- Integrates with a wide range of resource discovery systems

Cricket: Private location-support



No central beacon control or location database

Passive Listeners + Active Beacons

Finding the distance

- Basic formula: distance = speed * time
  - want to find the distance
  - we know the speed
- How do we figure out time?
  - there are several choices
- 1: Measure round-trip time (like radar)
  - this violates some of our goals -- which ones?

Finding the distance

- 2: Synchronized clocks
  - receiver knows exactly when transmitter sent signal
    - need very accurate clocks
  - send a signal to first sync clocks ; then send second signal
    - does this work?

Finding the distance

- 3: Use two different speed signals
  - both start at same time

    $d = s_1 * t_1$

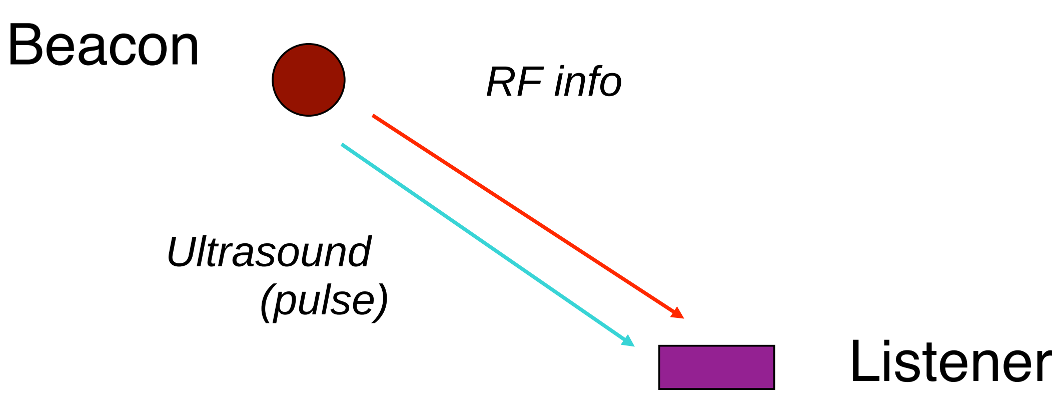
    $d = s_2 * t_2$
  - We measure delay: $m = t_1 - t_2$

    $t_2 = m * s_1/(s_2 - s_1)$

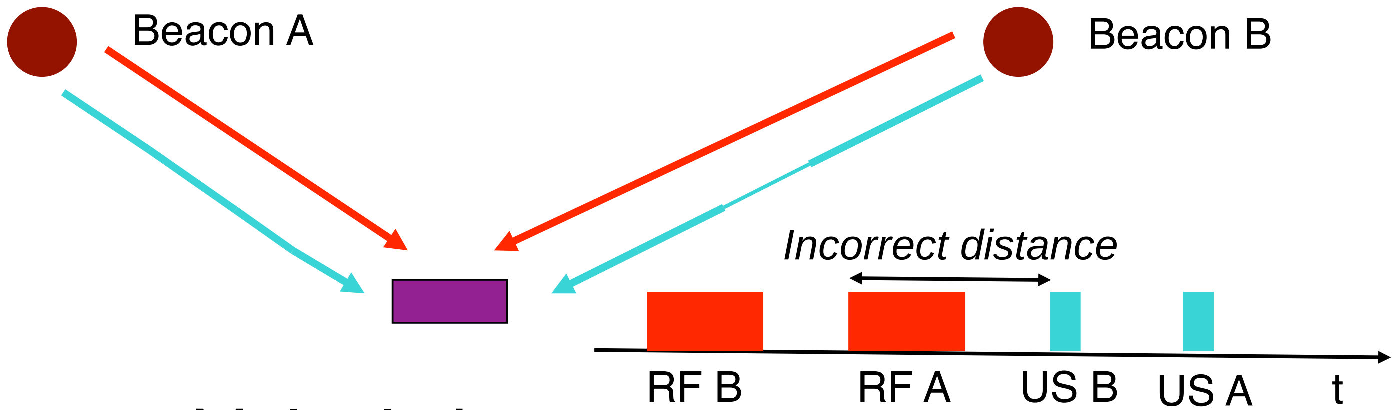
    $d = m * s_2 s_1 /(s_2 - s_1)$
- Cricket does this
  - RF is really fast compared to US

Location Estimation

- **Distance estimation via coupled RF and ultrasonic signals**
  - Beacons send information on the RF channel with concurrent ultrasonic pulse



Uncoordinated Beacons



- Multiple beacon transmissions are uncoordinated
- Different beacon transmissions can interfere
  - causes inaccurate distance measurements at the listener

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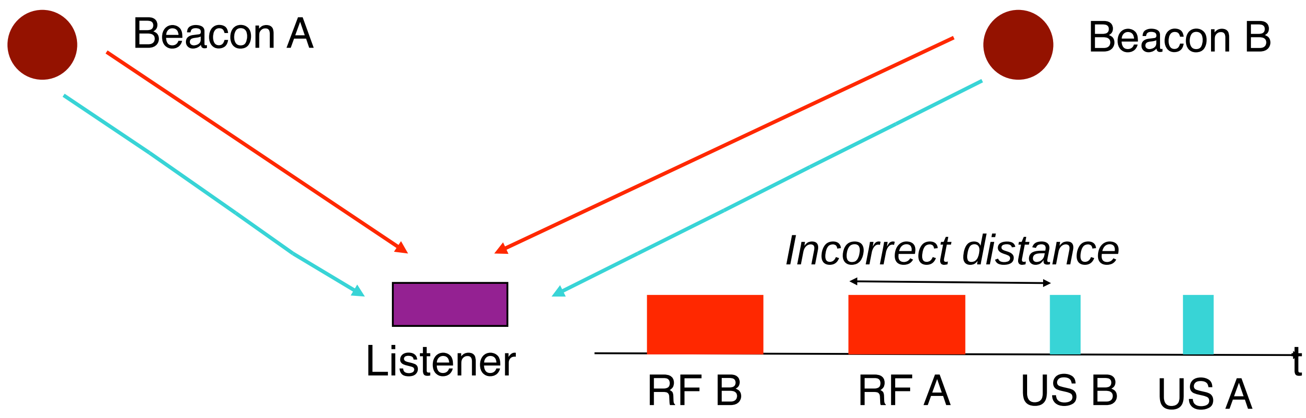
Multiple Beacons



- **Beacon transmissions are uncoordinated**
- **Ultrasonic signals reflect heavily**
- **Ultrasonic signals are pulses (no data)**

These make the correlation problem hard and can lead to incorrect distance estimates

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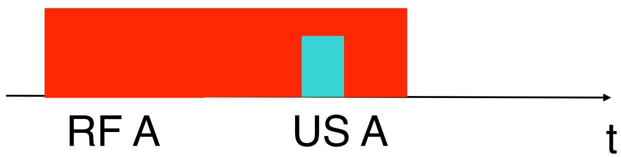
Solution

- Carrier-sense + randomized transmission
  - reduce chance of concurrent beacons
- Bounding stray signal interference
  - envelop all ultrasonic signals with RF
- Listener inference algorithm
  - Processing distance samples to estimate location

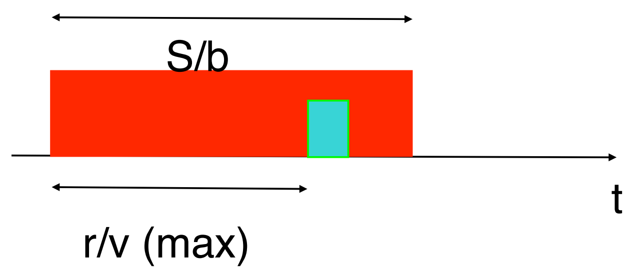
Bounding Stray Signal Interference



- **Engineer RF range to be larger than ultrasonic range**
  – Ensures that if listener can hear ultrasound, corresponding RF will also be heard

Bounding Stray Signal Interference

S = size of space advertisement
b = RF bit rate
r = ultrasound range
v = velocity of ultrasound

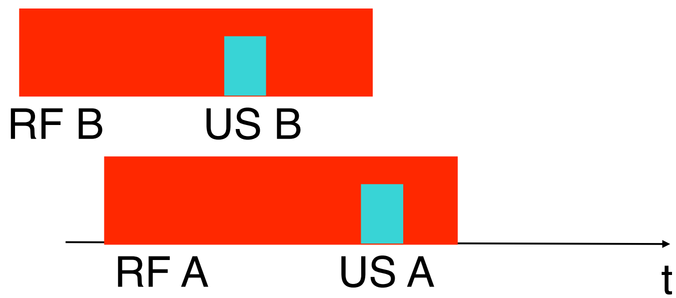


$$\frac{S}{b} > \frac{r}{v}$$

(RF transmission time) (Max. RF-US separation at the listener)

- **No "unaccompanied" ultrasonic signal can be valid!**

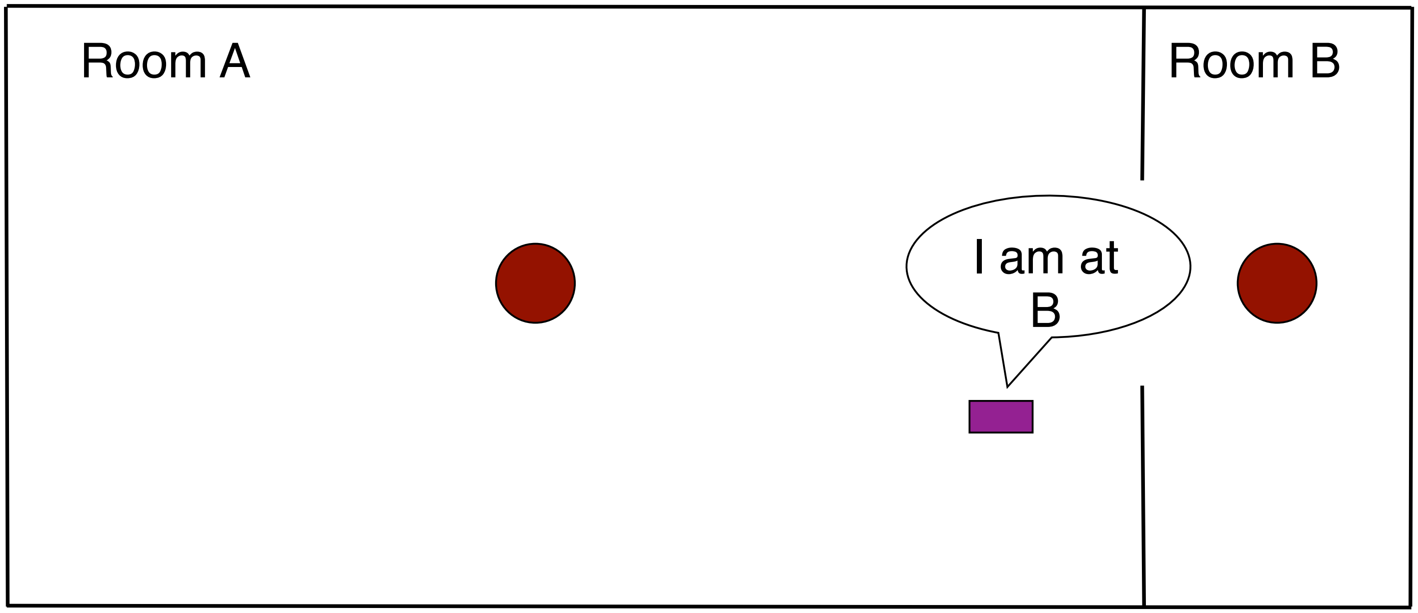
Bounding stray signal interference



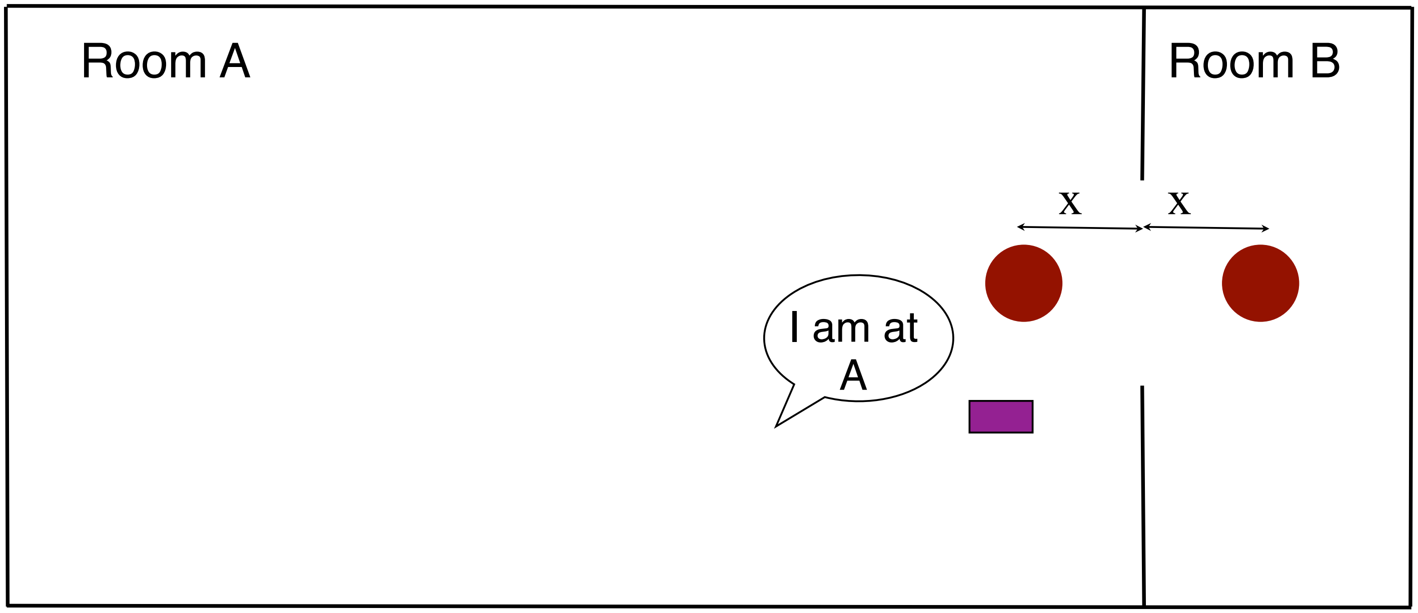
- **Envelop ultrasound by RF**
- **Interfering ultrasound causes RF signals to collide**
- **Listener does a block parity error check**

– The reading is discarded...

Problem: Closest Beacon May Not Reflect Correct Space



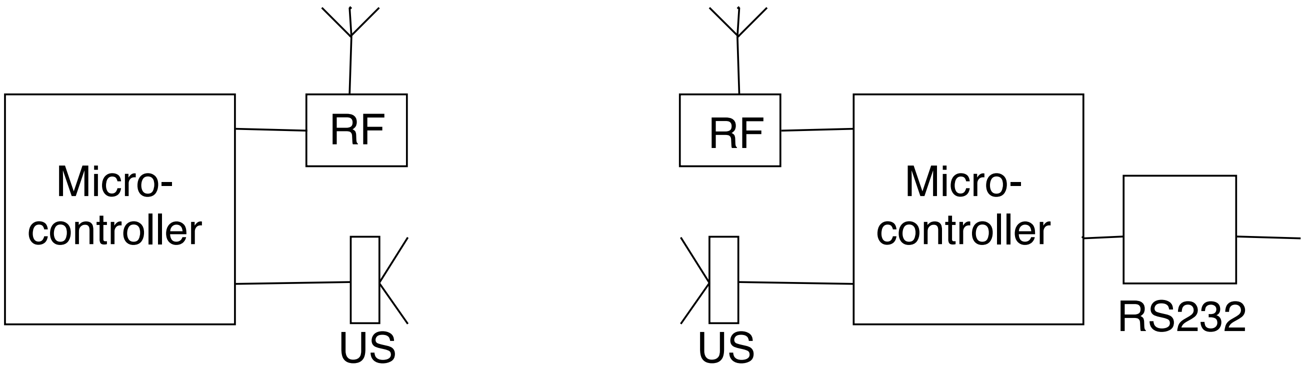
Correct Beacon Placement



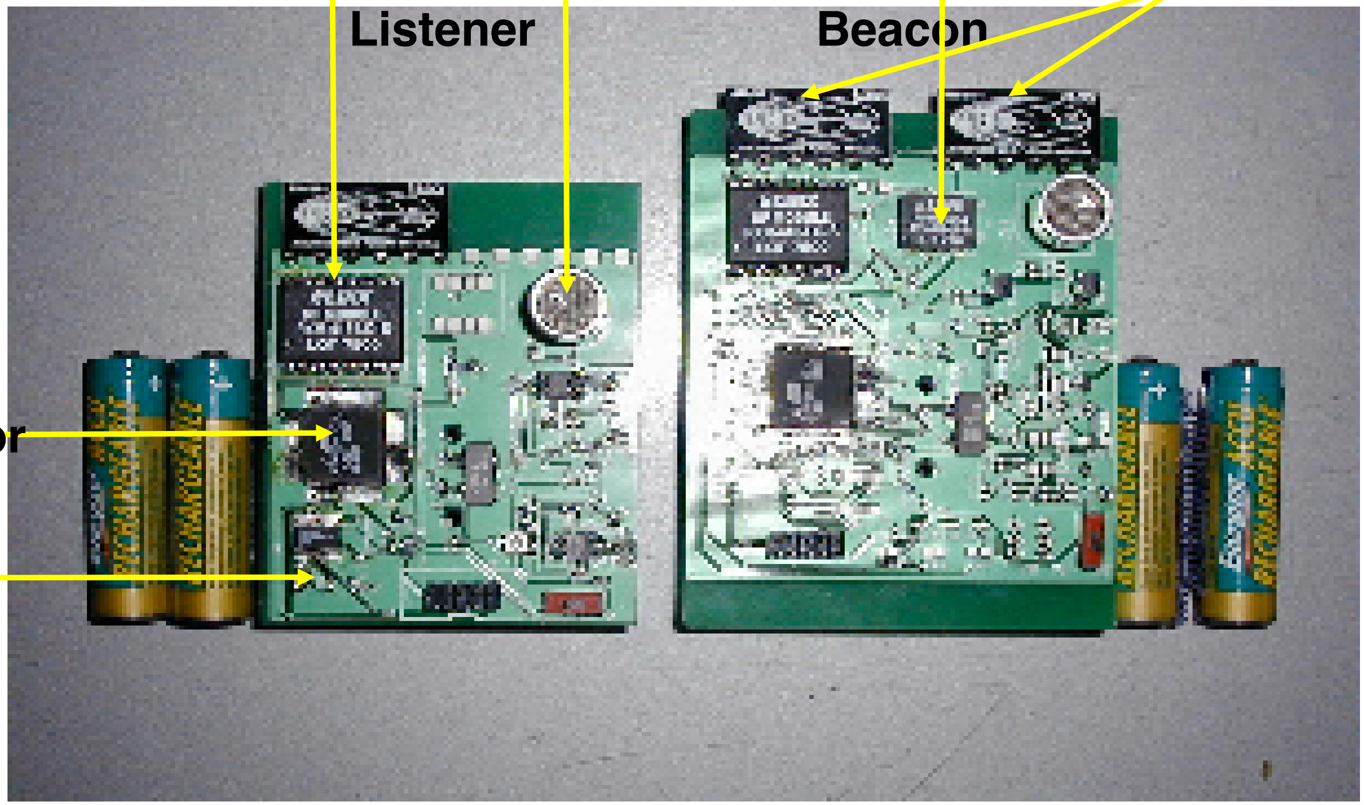
- **Position beacons to detect the boundary**
- **Multiple Beacons per space are possible**

Implementation

- **Cricket beacon and listener**

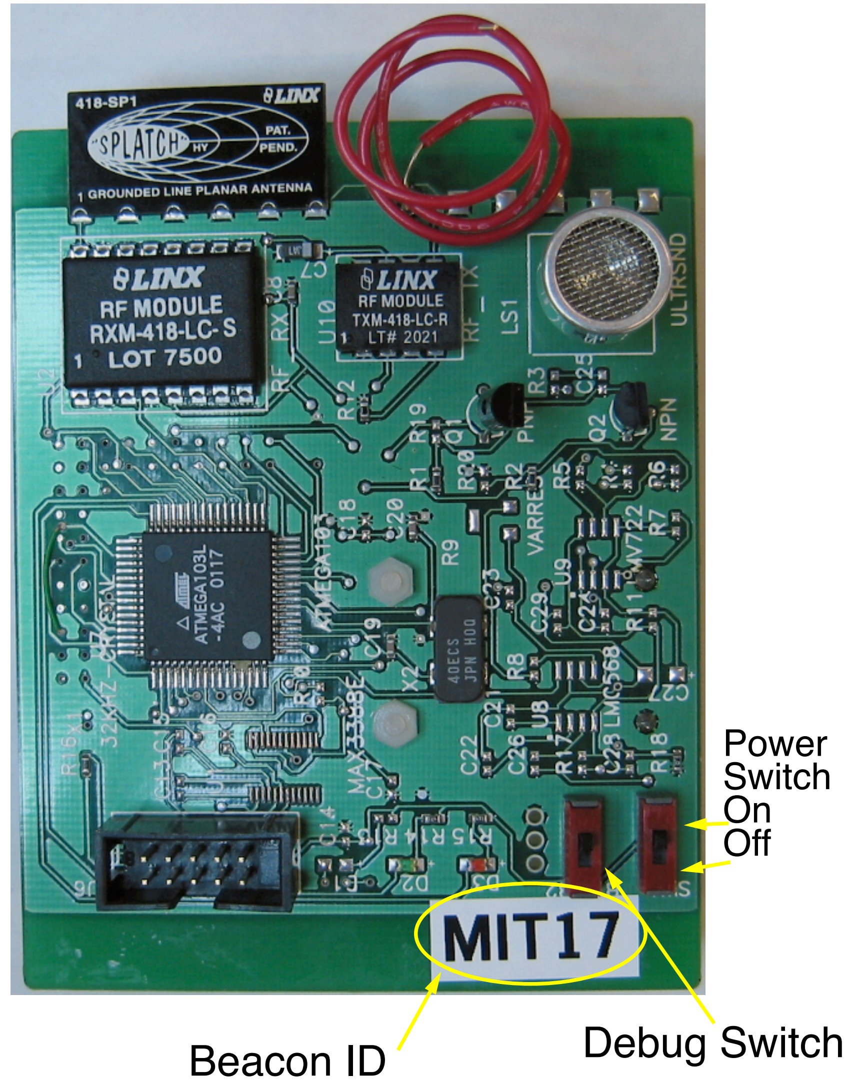


Cricket v1 Prototype



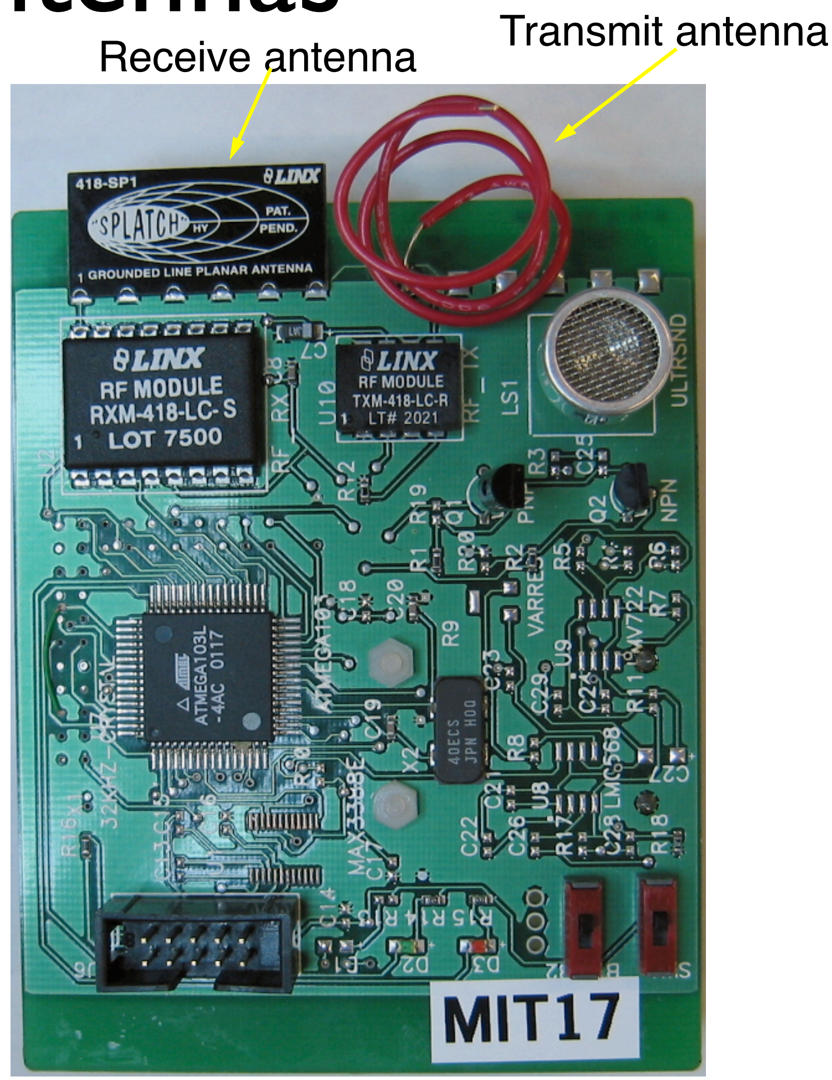
Cricket Beacon LEDs

- Debug Switch = UP
  - Green LED = Transmit
  - Red LED = Carried Sensed
- Debug Switch = Down
  - Green LED = Every 5th transmission
- At Startup
  - LEDs flash version number
  - Red on, Green flash count = Major #
  - Green on, Red flash count = Minor #
- Power Switch
  - Up = On



Cricket Beacon Antennas

- Receive Antenna
  - For sensing transmission of other beacons
- Transmit Antenna
  - Limit transmission distance
  - Should not touch ultrasound
  - Should not cover receive antenna



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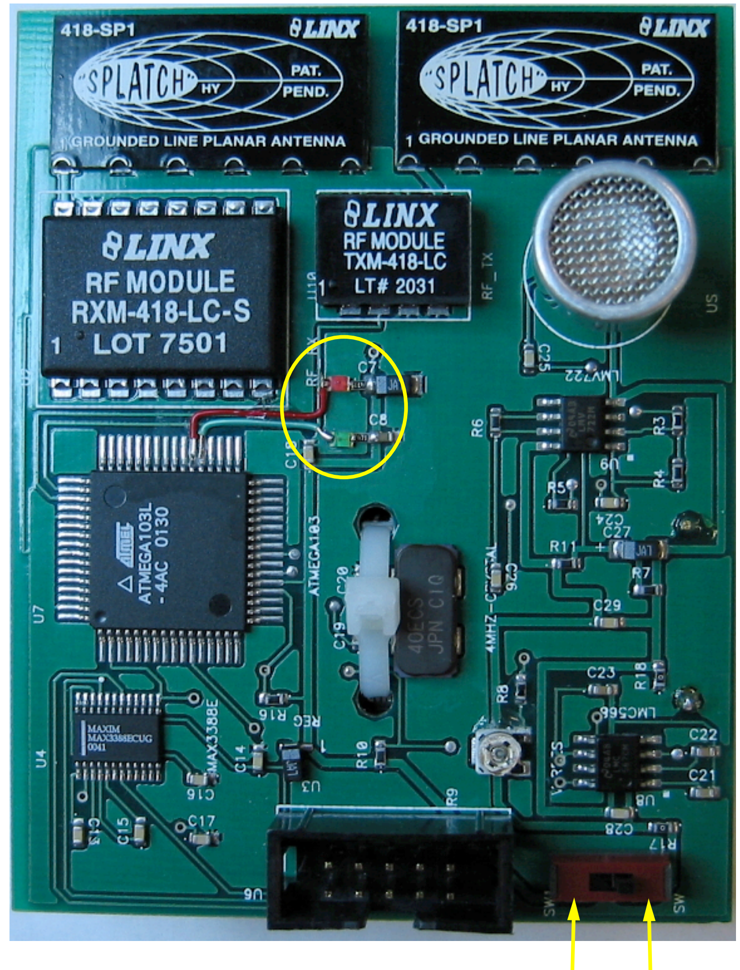
Listener LEDs

- Green Flash
  - Received valid RF and ultrasound
- Red Flash Once
  - Received Radio, but not ultrasound
- Red+Green Flash
  - RF Error (e.g., parity error)
- Red and Green always on
  - Listener not working correctly
- Power On
  - Both LEDs flash together once



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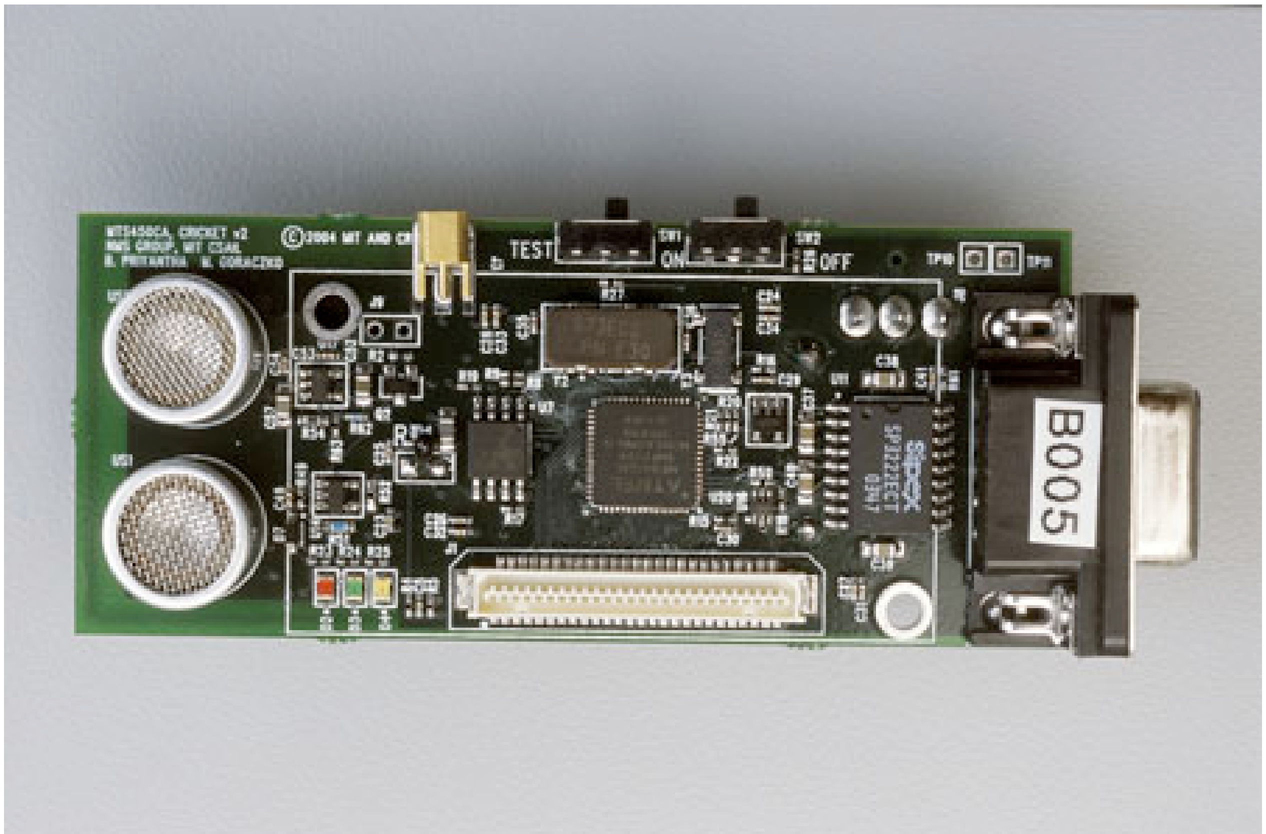
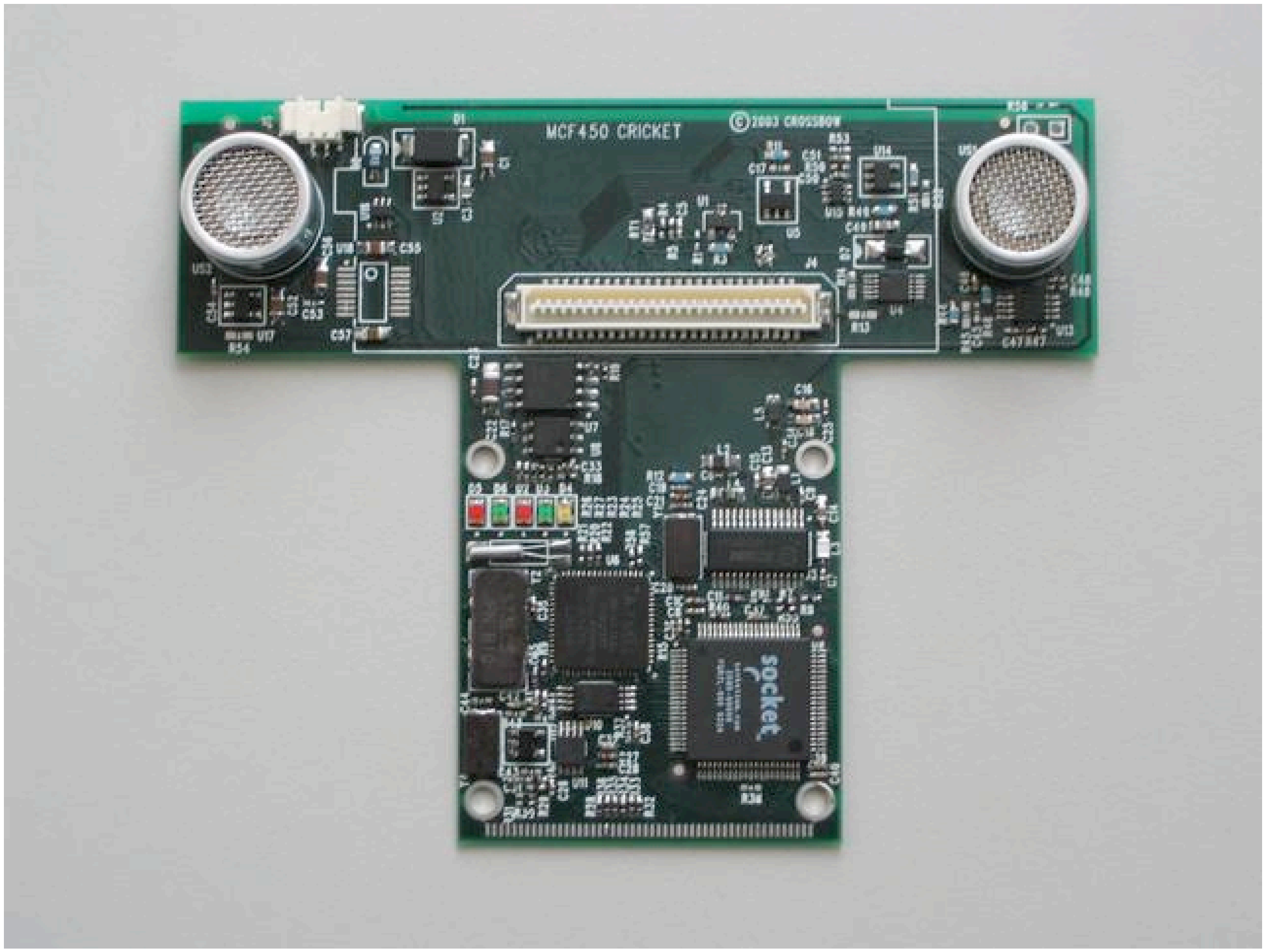
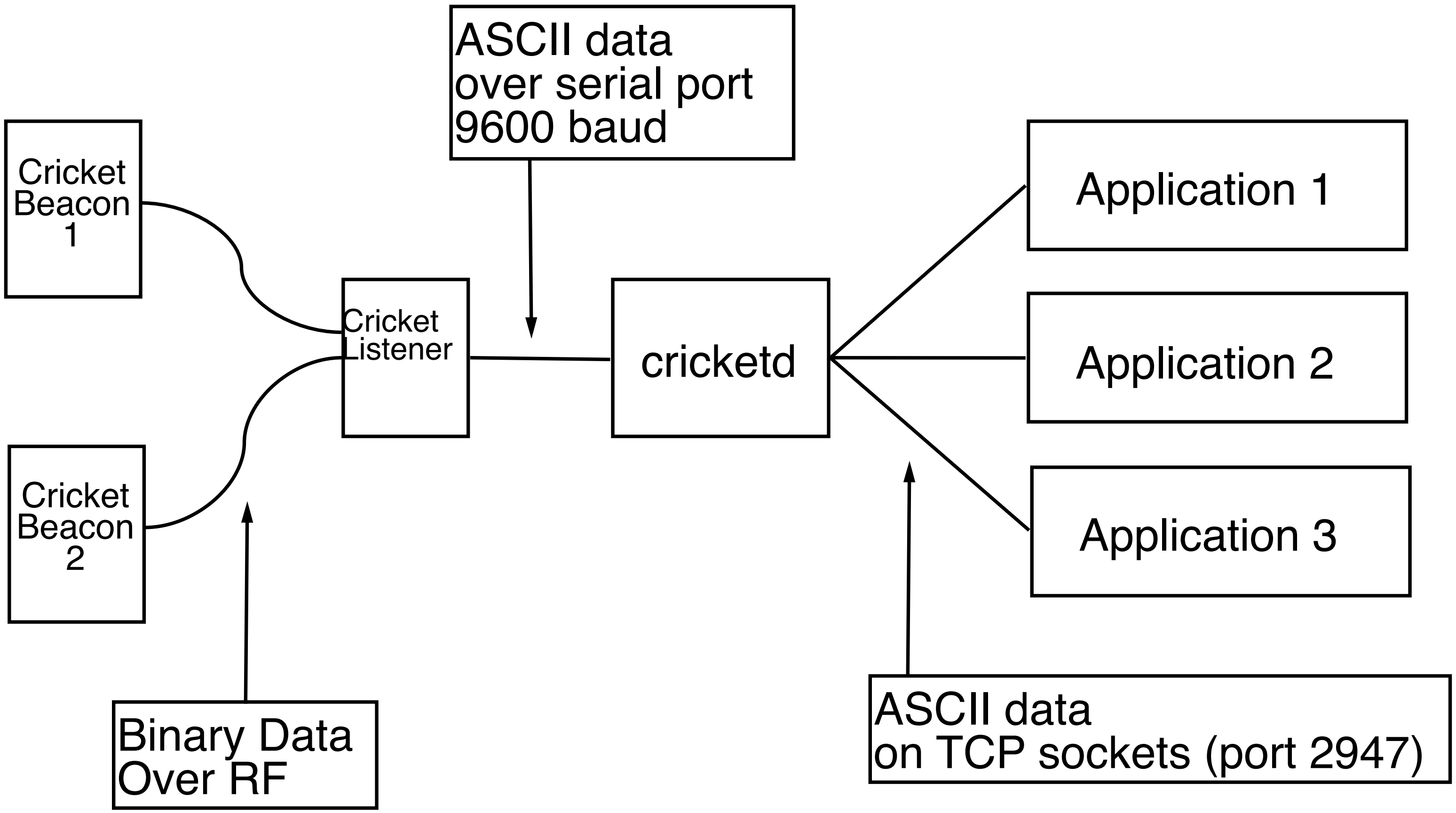

TEST
ON
OFF
B005


MCF450 CRICKET
©2003 CROSSBOW

Cricket Version 2

- Each device can be configured as:
  - listener
  - beacon
  - listener & beacon
- Same H/W as Berkeley Mote
  - Runs tiny-os
  - Connector for sensors
- Lots of configurations possible
  - need special connector to configure

Software Components

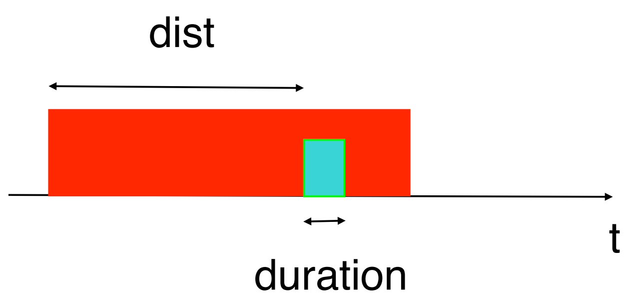


cricketd

- Background program (demon) that reads serial port and writes data to a socket
- Command line arguments (defaults work correctly on ipaq)
  - -T k Version 3 Listeners (with LEDs) (default)
  - -T c Version 2 Listeners (without LEDs)
  - -S <port> Socket port number (default is 2947)
  - -p <dev> Serial port device name (default "/dev/ttySA0")
  - -s <baud> Baud rate of serial port (default is 9600)
  - -h Help
  - -D <num> Debug level

Cricket Listener Output

- Strings reported from Listeners
  - When good RF and good ultrasound pulse heard:
    - "$Cricket2,ver=3.0,space=MIT7,id=20,dist=4F,duration=1A"
  - When only good RF heard, no ultrasound heard:
    - "$Cricket2,ver=3.0,space=MIT7,id=20"
  - When RF detected, but parity error detected:
    - "$Cricket2,ver=3.0,err=rf"



Speed of Sound

- Listener reports distance and duration in 15.625 KHz counter cycles (64 microseconds each).
- Assume speed of sound is 344.49 m/s then 22.047 mm/cycle
- For 343.75 m/s = 22 mm/cycle
- Need to subtract 36 units for delay from end of RF to start of US transmission.

So where are you?

- Telnet to cricketd (on correct port)
- Get names of beacons within range
- Get distances from beacons
- Lookup beacon location in database
  - Or use beacon name (longer transmission)
- Triangulate (compensate for temp)

So where are you?

- Beacon name may tell you room
  - That may be enough
- May want to know relative movements
  - As you walk around the room
  - No climbing on tables
- Can you do it using two beacons?
  - Can you do it without calibration?

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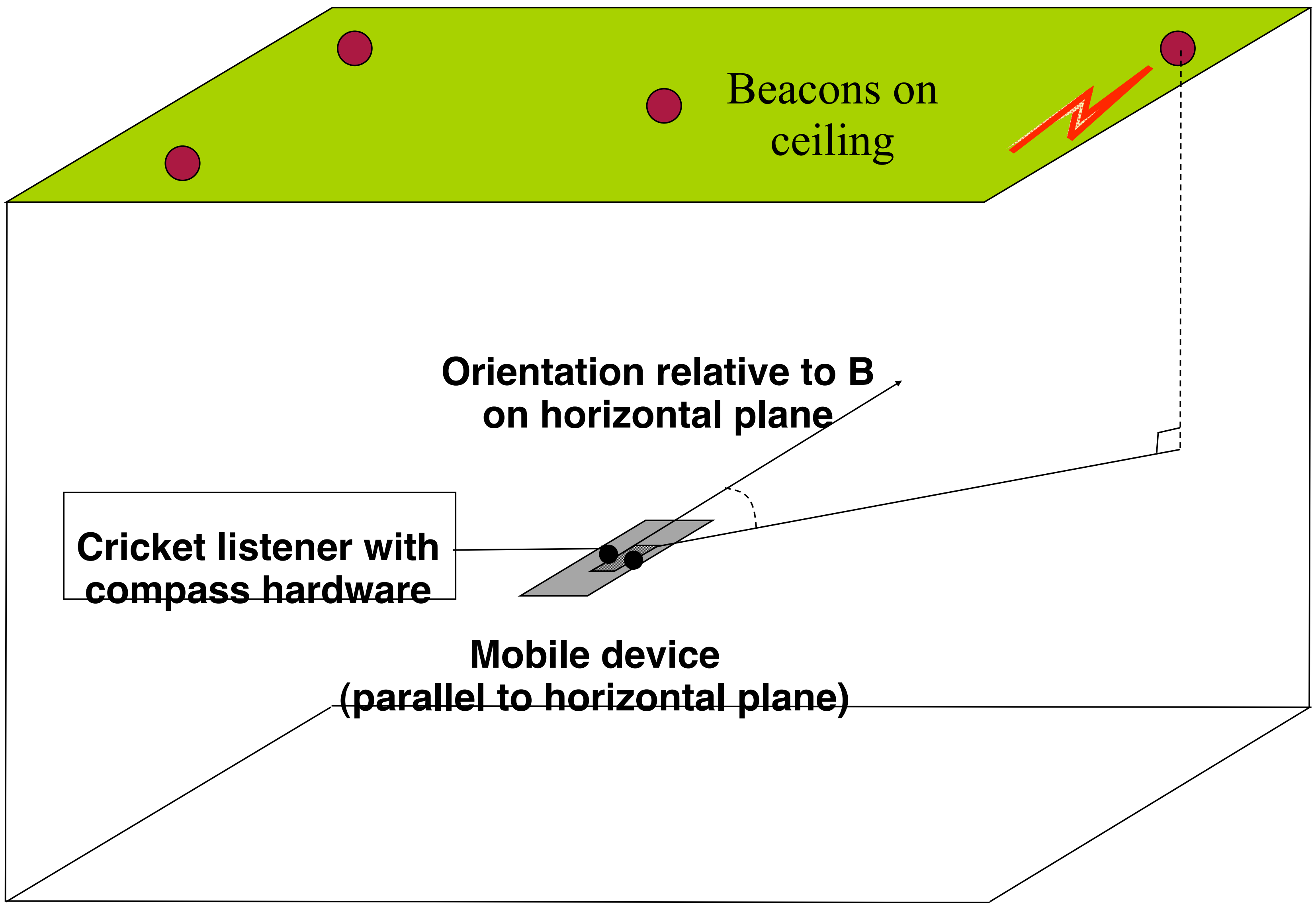
Two beacons

- Put them along the wall
- Come very close to one of them
- Now know distance between them
- Given distances from both
  - Before and now (d1,d2) & (e1,e2)
  - Can find relative movement
  - Two solutions! No problem, why?
  - Ex. Doom virtual world

Orientation



Hardware Design

- Main site for cricket stuff:

http://nms.csail.mit.edu/cricket

  - http://nms.csail.mit.edu/cricket/fab
    - Need user & password
  - http://nms.csail.mit.edu/cricket/distrib
    - Need user & password

More accurate readings

- Readings are not accurate -- reflections, noise, etc. cause inaccurate values
- How to compute current position?
- How to compute when in motion?

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When standing still

- Values still fluctuate
- Want to average over many values
  - takes long time
- Want to ignore "outliers" -- the values that do not make sense

Least Squares Method

$$\sum_{i=1}^{n}(||\hat{\phi}_i - p_i|| - d_i)^2$$

- Given a bunch of readings, find an estimated location that minimizes:
  - d is distance from beacon, p is beacon location, and phi is estimated location
  - (phi - p) is estimated distance from beacon
  - ((phi-p) - d)**2 is square of difference
  - minimize the sum over all measurements

CSAIL

Kalman Filters

- Each measurement has a probability density function associated with it.
- It is specified by standard deviation (sigma) and by variance (sigma squared)
- Given two measurements, each with its own probability or conditional density
  - compute probability density function around new location as a weighted average of both

CSAIL

Kalman Filters for dynamic system (when moving)

- In addition to location measurement (and its probability function) also have
  - velocity plus noise
- compute guess as to new position in future
  - based on time and velocity.
- The velocity noise factor
  - spreads out the probability density function of the location in the future.
- New real measurements combine with predicted location as before
  - measurements usually have more accuracy than predicted value: so get more weight

When tracking moving cricket

- Least squares does not work because hear beacons at different times
- Use Kalman Filters
  - combined with Least Squares and outlier rejection

Hybrid Approach

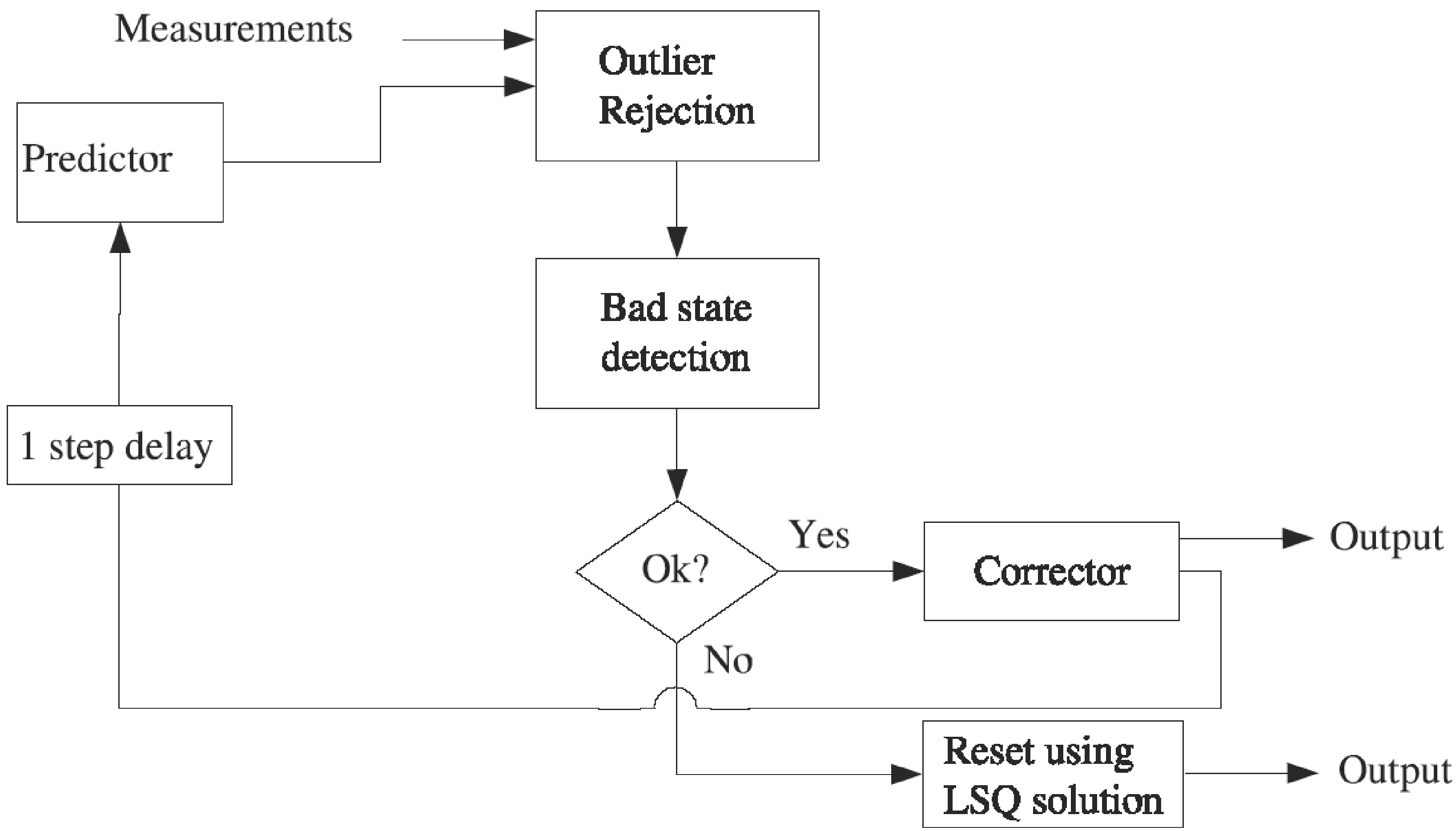

Figure 3: Flow chart for the tracking algorithm. The picture shows outlier rejection and LSQ explicitly; all the other steps are part of the extended Kalman filter. The "measurements" are the distance samples obtained as triples. The "output" at each stage is the position estimate $\hat{\phi}$.

When Kalman Filter goes bad ...

- Reject new values that look bad
  - but if too many get rejected then maybe those are the right ones
- To get back on track, use Least Squares
  - but need simultaneity
  - how to do that?
- Listener sends special signal with a nonce
  - heard by all listeners
  - all beacons then know distance for listener
  - beacons send back the distance with nonce
  - listener gets data as if all beacons chipped at same time

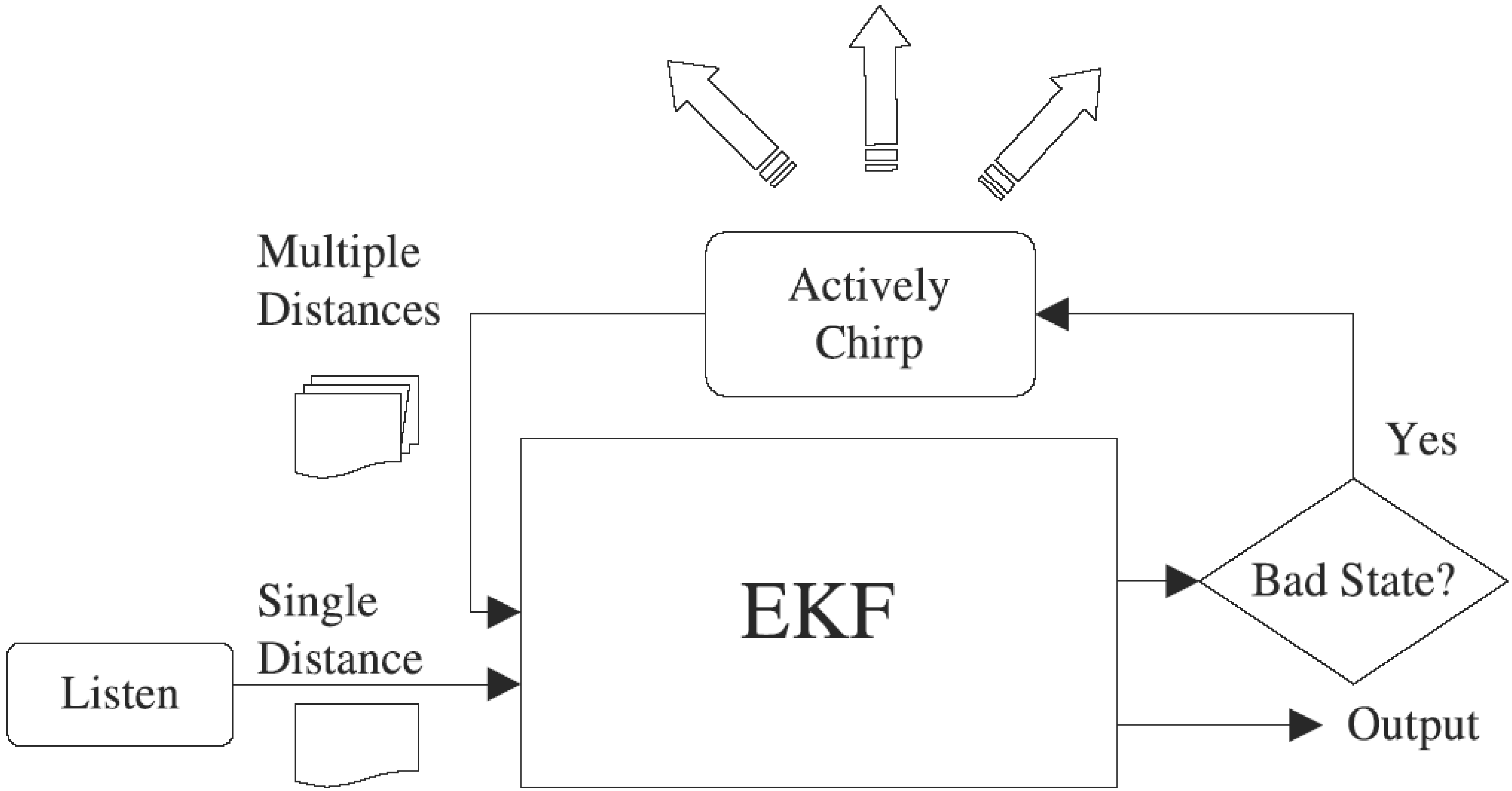

Figure 4: Flow chart of a mobile device using a hybrid architecture.

Alternative Method

- Detect with cricket is at rest
- Not so easy to do
  - we use tilt meters & camera
  - tilt meters are noisy
  - optical flow of camera
    - not fool-proof