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TRAVEL TIMES USING BLUETOOTH

Agenda

- How does Bluetooth work?
- For travel time purposes?
- What about in the future?

How Does Bluetooth Work?

- Bluetooth Architecture
- Typical usage (for users, not traffic!)
- Media Access Control (MAC) addresses
- End user devices

Bluetooth Classes

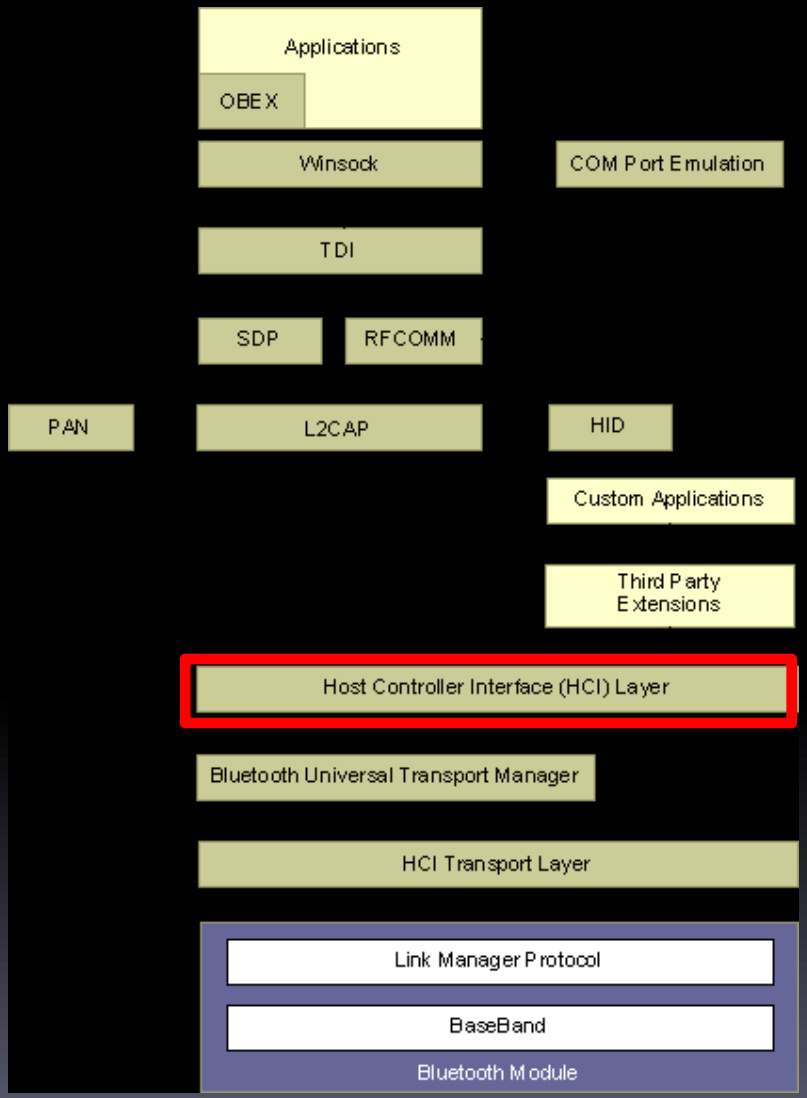
- Class 1 (some adapters, industrial applications)
  - Power consumption: 100 mW
  - Range: ~100 meters
- Class 2 (phones, headsets, laptops, mice)
  - Power consumption: 2.5 mW
  - Range: ~10 meters
- Class 3 (not typically used)
  - Power consumption: 1 mW
  - Range: ~1 meter

Bluetooth Stacks

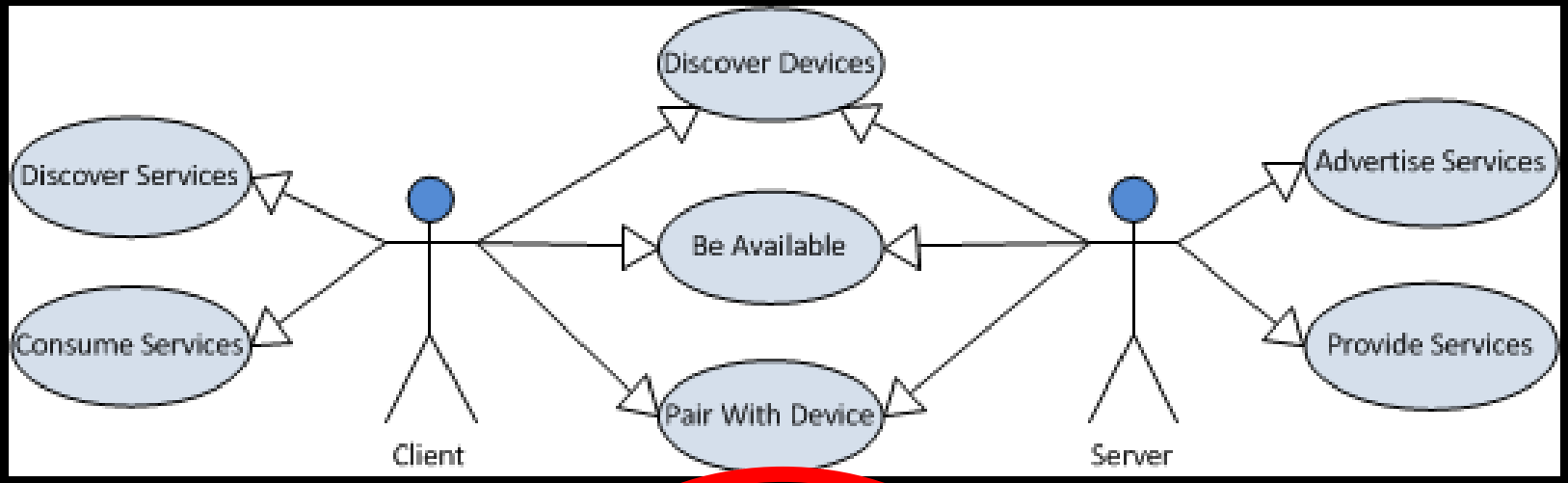
- Adapters will support one or more stacks, but not all are supported by an adapter
- Linux
  - BlueZ
- Windows
  - Microsoft
  - Widcomm
  - Toshiba

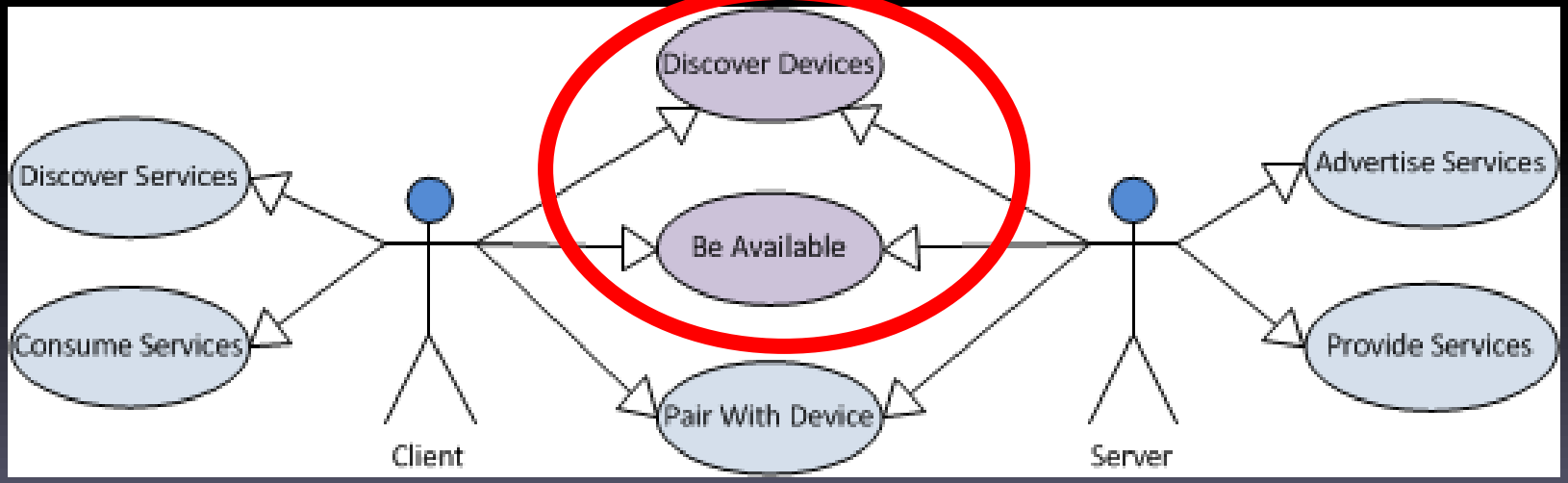
Stack Architecture

- HCI (Host Controller Interface)
  - Main interface to the hardware
  - Can invoke via command line
- Inquiry
  - Discovers other Bluetooth devices
  - Only command required for traffic purposes



Bluetooth Use Cases





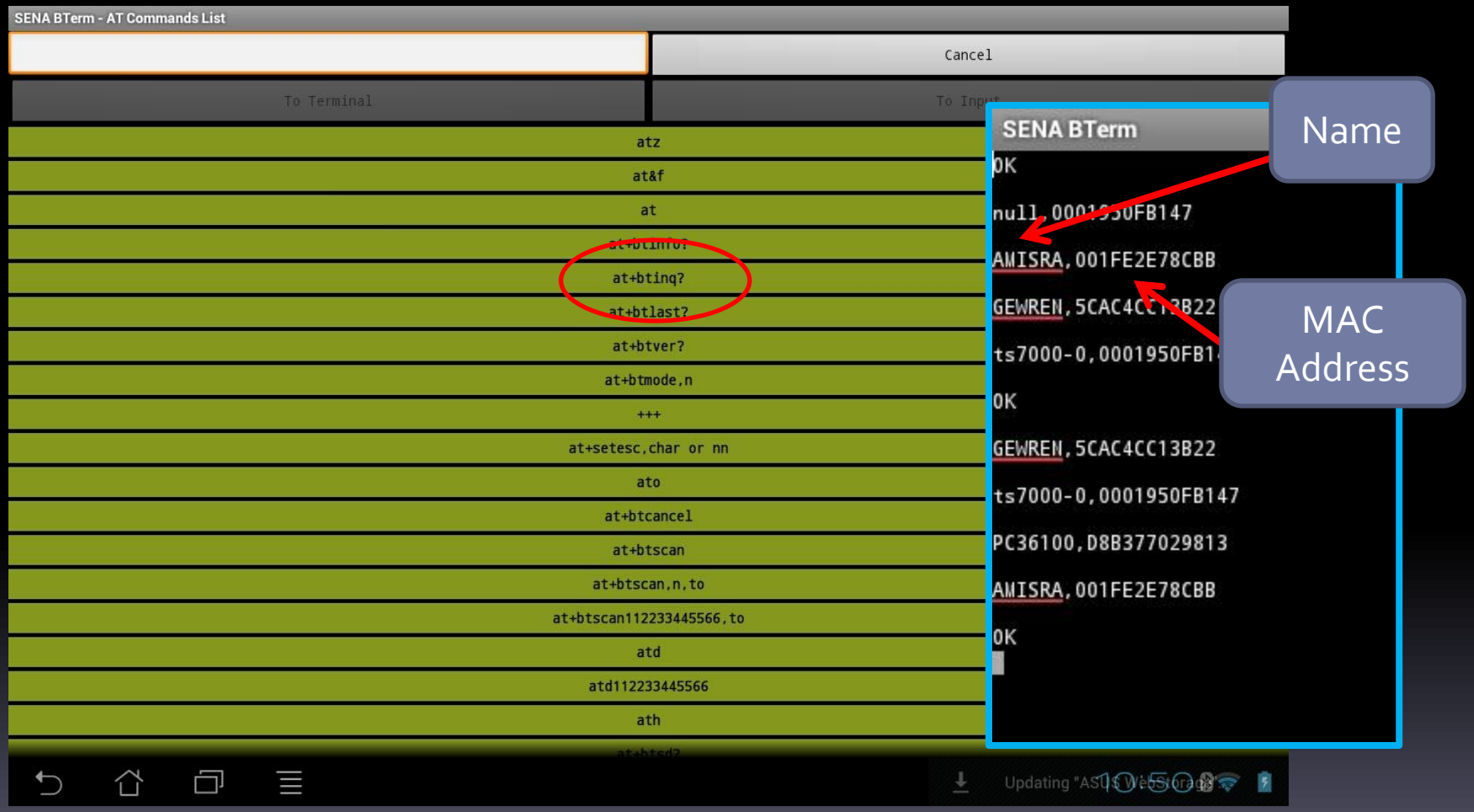
How Is Bluetooth Used?

- Pair two devices (headset and phone, e.g.)
  - For pairing, one device is made discoverable
  - Second device searches or scans
- Once paired, neither has be discoverable to connect
  - Save knowledge of paired devices
  - Already have the MAC address
- Once paired, list of available "services" is shared

Discovery—What Happens?

- Frequency hopping—79 bands for normal communication, 32 used for discovery
- One side is the master, other slave
  - Can switch, e.g., in headset pairing
    - During discovery, headset is master
    - Later connections, phone is master
- For our purposes, discovery is the end, no need to pair devices

SENA Blueterm



Discovery—What Do We Get?

- Name of the device
  - Most likely not unique
  - Devices of same type typically have the same name
  - May not receive during first detections
- *Bluetooth* MAC Address
  - **NOT** the device's WiMAX MACaddress
  - Not "tracked" with the device

MAC Addresses

- Similar to IP MAC addresses, Bluetooth devices have a (mostly) unique MAC address
  - Some cheaper dongles or headsets may use the same address for all
  - Even Sony Ericsson P900 phones had duplicate addresses!
- Can provide information on the device
  - Manufacturer
  - Type of device

Dissecting a MAC Address

00:0A:D9:EB:66:C7

00:0A:D9	EB:66:C7
Manufacturer Organizationally Unique Identifier (OUI)	Manufacturer determines these, may be grouped
Each manufacturer may have multiple OUIs (assigned by IEEE) May use particular number for specific device types	Should be unique, but no guarantees!

End User Devices

- Types of devices with Bluetooth
  - Laptops
  - Cell phones
  - Headsets
  - GPS units
  - Vehicles
  - MP3 players
  - And more…
- Not all are relevant for travel time usage

Atypical Usage

- BlueLon iQueue- http://www.bluelon.com/
  - Tracks passengers in security to provide wait times to travelers
  - Used in Heathrow, Belfast, Franklin airports
- Bluetrace- http://www.bluetrace.eu/
  - Tracks employees, shoppers, etc.
- Scanning concert-goers- http://hothardware.com/News/Bluetooth-Tracking-System-Monitors-Concert-Goers/

Agenda

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Bluetooth Traffic Products

Vendors with products

What are they using?

BAT Products

ACYCLICA

BlueCompass

Savari networks

Texas Transportation Institute

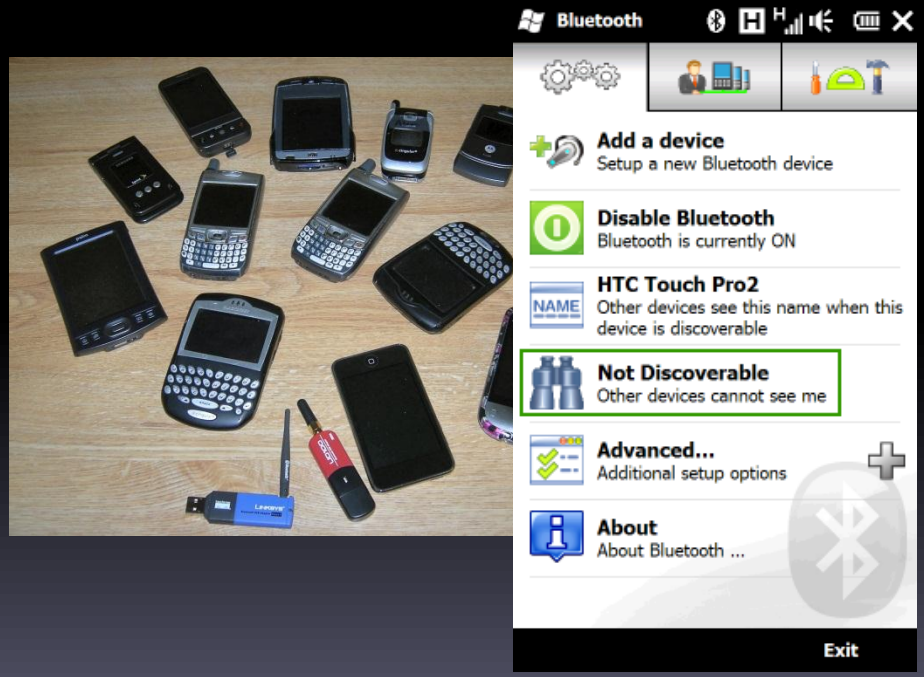
StreetWAVE™ - Bluetooth Trave

TRAFFICAST

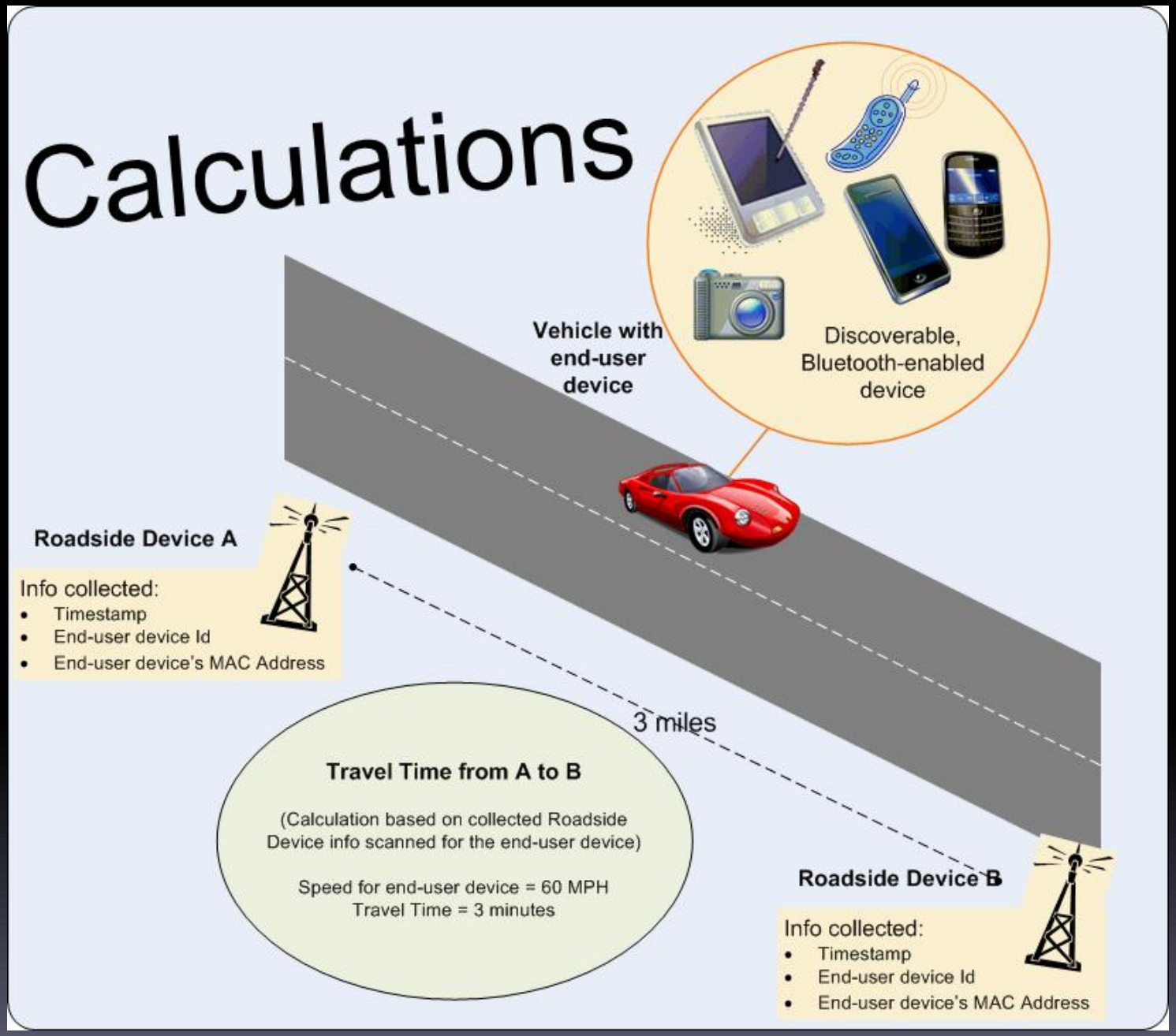
BlueTOAD

SPEEDS, TRAVEL TIMES & ORIGIN/DESTINATION

ACCURATE. RELIABLE. COST-EFFECTIVE.



Calculations



Why The Hype?

- Lower cost solution, often by an order of magnitude
- Does not require users to have tags or other equipment issued to them
- Roadside calculations are minimal, low power consumption
- Can be deployed with cellular modems and solar power where no infrastructure exists

Research: Potential Issues

- Is there sufficient data from scans?
- End user devices' Bluetooth mode
  - Must it be discoverable to be read?
- Is scanning effective at higher speeds?

Evaluate Feasibility

- Can scans be performed fast enough for highway speeds to be calculated?
- Can temperature rated equipment be assembled to create roadside-ready hardware?
- What about end user devices?
  - Are there enough to provide valid times?
  - Must the devices be in discoverable mode?
- What type of antennae are required for highway testing?

Roadside Device

Roadside Device Components

- Atom 450 processor
- Parani UD100 Bluetooth adapter w/operational temperature range of -20C to 70C and with antenna connector.
  - Temperature hardened devices uncommon
  - Can also requisition Bluetooth chips
- Focused directional antennas (9dBi and 14dBi).
- Omni-directional antennas (3dBi and 9dBi).

Testing Steps

- Develop prototype scanning process
- Evaluate antennae ranges and cone of effectiveness
- Test with known end user devices at varying speeds
- Analyze the data and determine next steps

Scanning Process

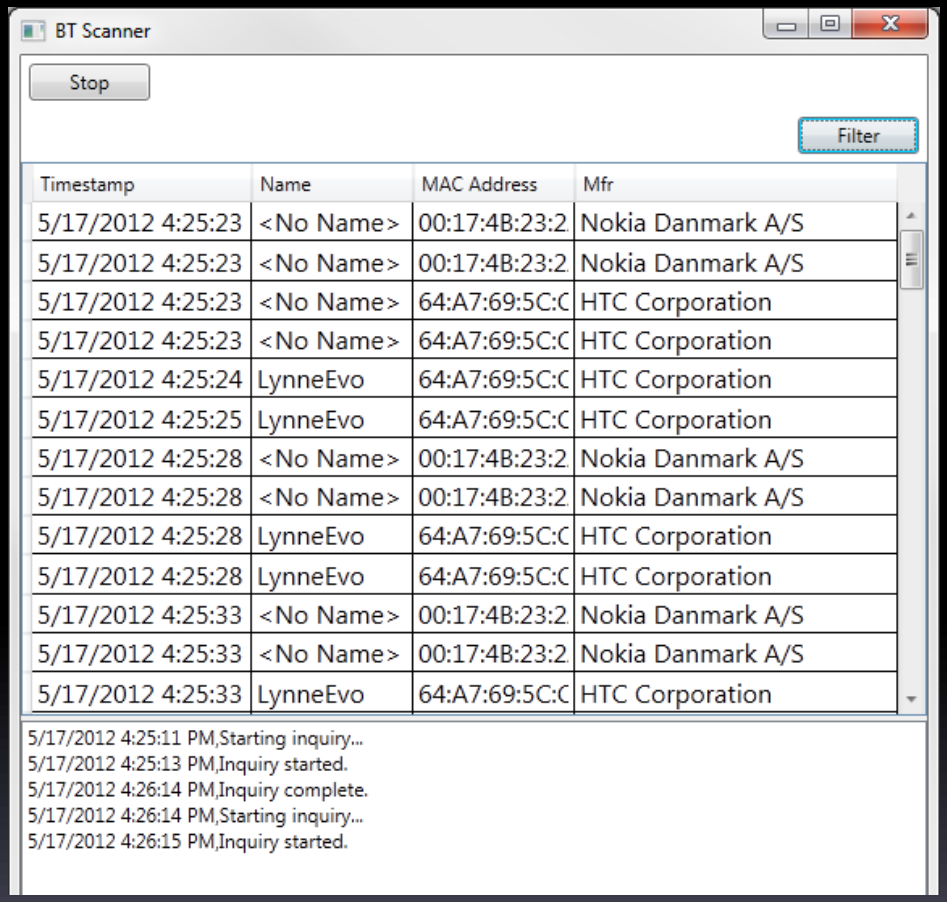
- Scanning utilizes a Bluetooth stack
  - Think of it as a "driver" to the operating system
  - Different on various operating systems
  - May be replaced by installation of Bluetooth adapter
- Scanning
  - Uses only one function of Bluetooth
  - Asks "Are you there?"
  - Devices reply with name and unique identifier

Initial Sample Scan

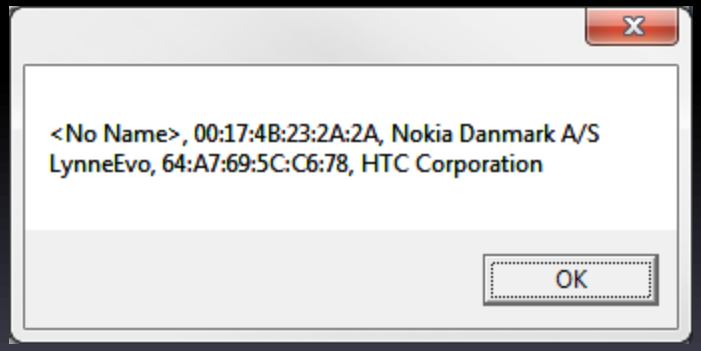
Administrator: C:\Windows\system32\cmd.exe

```
2010-10-07 14:43:49,Adam.nokia,00:17:4B:25:8D:23
2010-10-07 14:43:49,Adam.nokia,00:17:4B:25:8D:23
2010-10-07 14:43:49,Mickey nokia,00:1E:A3:8D:2C:41
2010-10-07 14:43:49,Mickey nokia,00:1E:A3:8D:2C:41
2010-10-07 14:43:49,treopaul,00:07:E0:9E:EF:FA
2010-10-07 14:43:49,treopaul,00:07:E0:9E:EF:FA
2010-10-07 14:43:49,Adam.nokia,00:17:4B:25:8D:23
2010-10-07 14:43:49,Adam.nokia,00:17:4B:25:8D:23
2010-10-07 14:43:49,HTC73,00:21:BA:D0:13:24
2010-10-07 14:43:49,HTC73,00:21:BA:D0:13:24
2010-10-07 14:43:49,HTC73,00:21:BA:D0:13:24
2010-10-07 14:43:49,HTC73,00:21:BA:D0:13:24
2010-10-07 14:43:49,treopaul,00:07:E0:9E:EF:FA
2010-10-07 14:43:49,treopaul,00:07:E0:9E:EF:FA
2010-10-07 14:43:49,Adam.nokia,00:17:4B:25:8D:23
2010-10-07 14:43:49,Adam.nokia,00:17:4B:25:8D:23
2010-10-07 14:43:49,Mickey nokia,00:1E:A3:8D:2C:41
2010-10-07 14:43:49,Mickey nokia,00:1E:A3:8D:2C:41
2010-10-07 14:43:50,Mickey nokia,00:1E:A3:8D:2C:41
2010-10-07 14:43:50,Mickey nokia,00:1E:A3:8D:2C:41
2010-10-07 14:43:50,SunGuide┤óΓé¼Γäós iPod,7C:6D:62:5F:74:C3
2010-10-07 14:43:50,SunGuide┤óΓé¼Γäós iPod,7C:6D:62:5F:74:C3
2010-10-07 14:43:50,SunGuide┤óΓé¼Γäós iPod,7C:6D:62:5F:74:C3
2010-10-07 14:43:50,SunGuide┤óΓé¼Γäós iPod,7C:6D:62:5F:74:C3
2010-10-07 14:43:51,Adam.nokia,00:17:4B:25:8D:23
```

Demo Screenshots



- Continually running inquiries
- Filtered to distinct MAC addresses



Bluetooth Stacks Tested

- Linux default (BlueZ)
- Windows default
- Widcomm

Stack Limitations

- BlueZ and Windows default had limitations
  - Scans are synchronous, no devices are returned until the scan is complete
    - May cause the matching to produce inaccurate time (depending on distance between units)
  - Reports each device a maximum of once per scan
    - No way to know if the device was found at the beginning or end of scan—same problems as synchronous scanning
  - Not all devices returned in each scan
    - Sometimes 2, 4, 6, up to a maximum of eight devices returned per scan
    - Could not find our 12 known devices in any one scan.
    - And this is while stationary!
- Functionality of stacks were not suitable for this purpose

Selected Bluetooth Stack

- Widcomm
  - Performs scanning asynchronously, each device is returned as found
  - May report each device many times during a scan
  - Found all of the test end user devices for each scan completed in a stationary manner
  - Suitable for our purposes!

Test Track

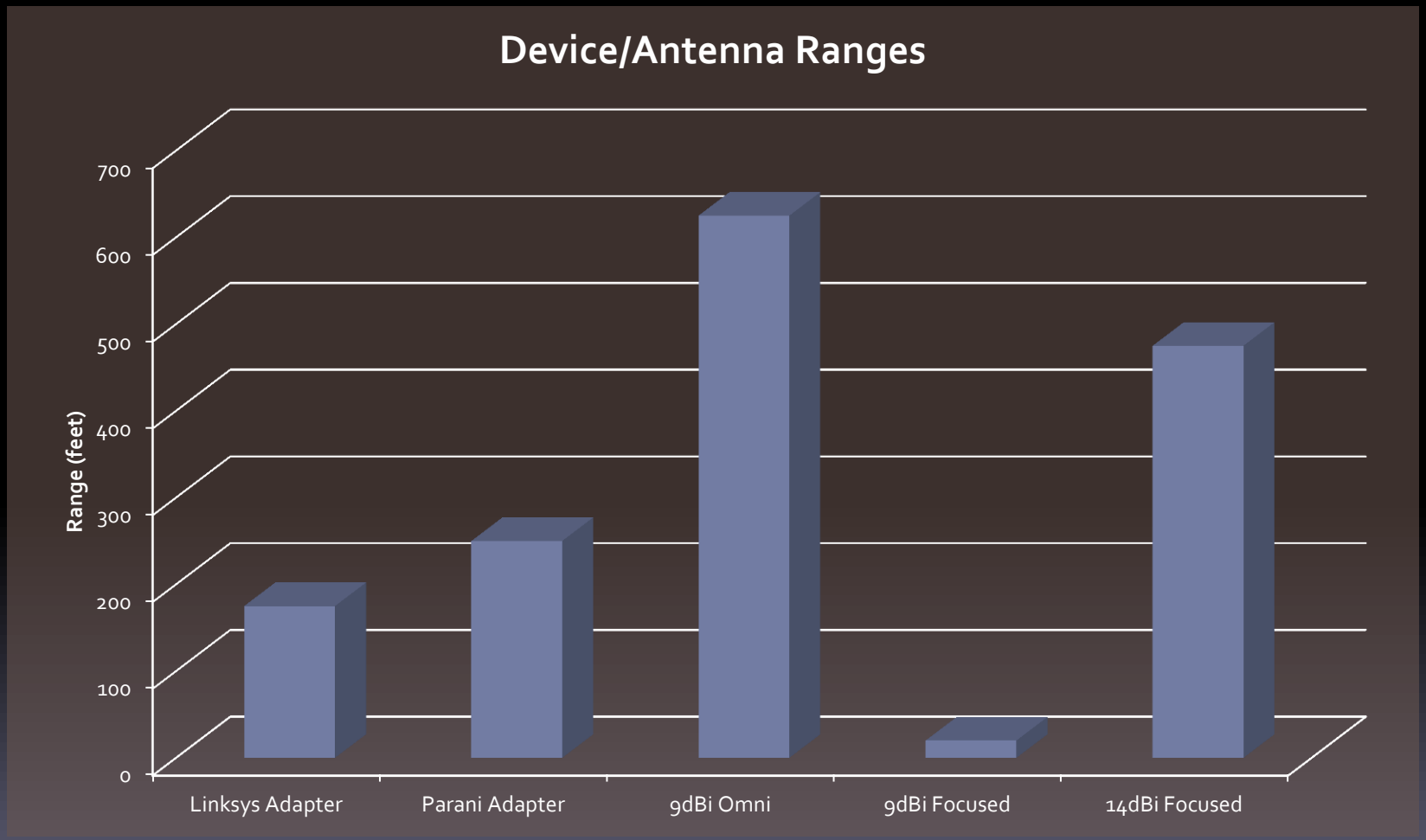
- Next, we took the testing out to the track

- Antenna range tests were performed with vehicles at known speeds with single end device
- Reads were tracked at various distance intervals

Antenna Range

- Parani adapter allowed external antennae to be added
- The adapter with and without antennae were tested for range
- Results showed the Parani range to be adequate for many highway situations
- Antennae attenuators would be required if antenna was added to extend the range

Antenna Comparisons

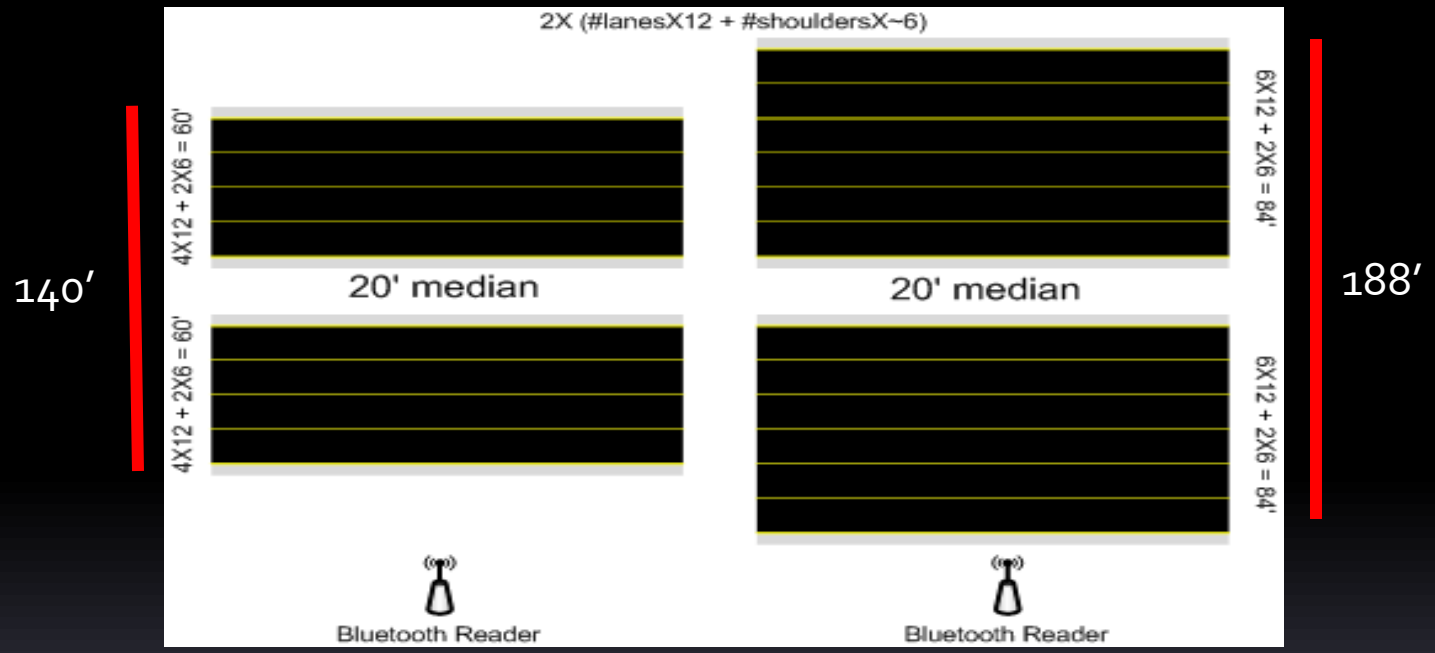


Antenna Observations

- Expectation was:
  - Focused antenna = greater forward-facing range than omni
  - Focused antenna < lateral range than omni
- Reality:
  - Omni-directional of the same or lesser db had a greater forward-facing range
  - Focused antenna had a much larger lateral range than specifications showed, but less than omni

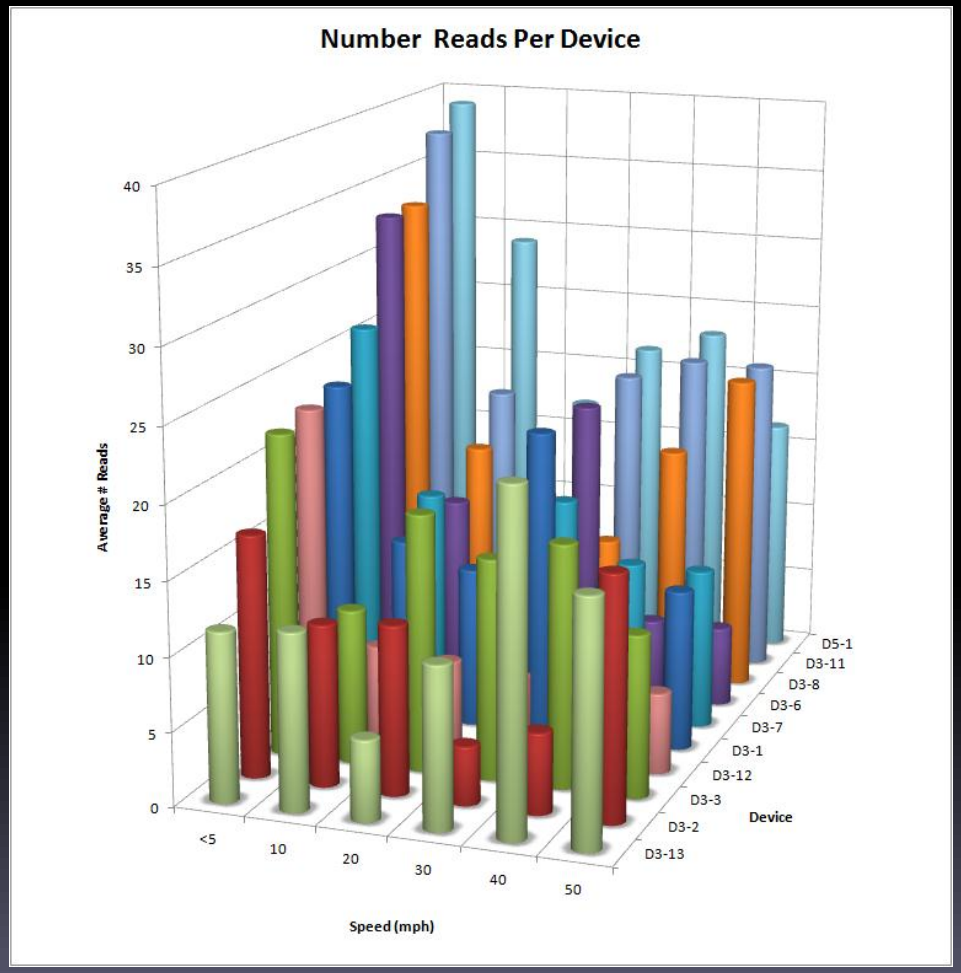
Highway Ranges

- Parani adapter on its own appeared to have an adequate range for most highway applications



- For restricting scanning distance, might need an attenuator in some configurations

Raw Device Reads



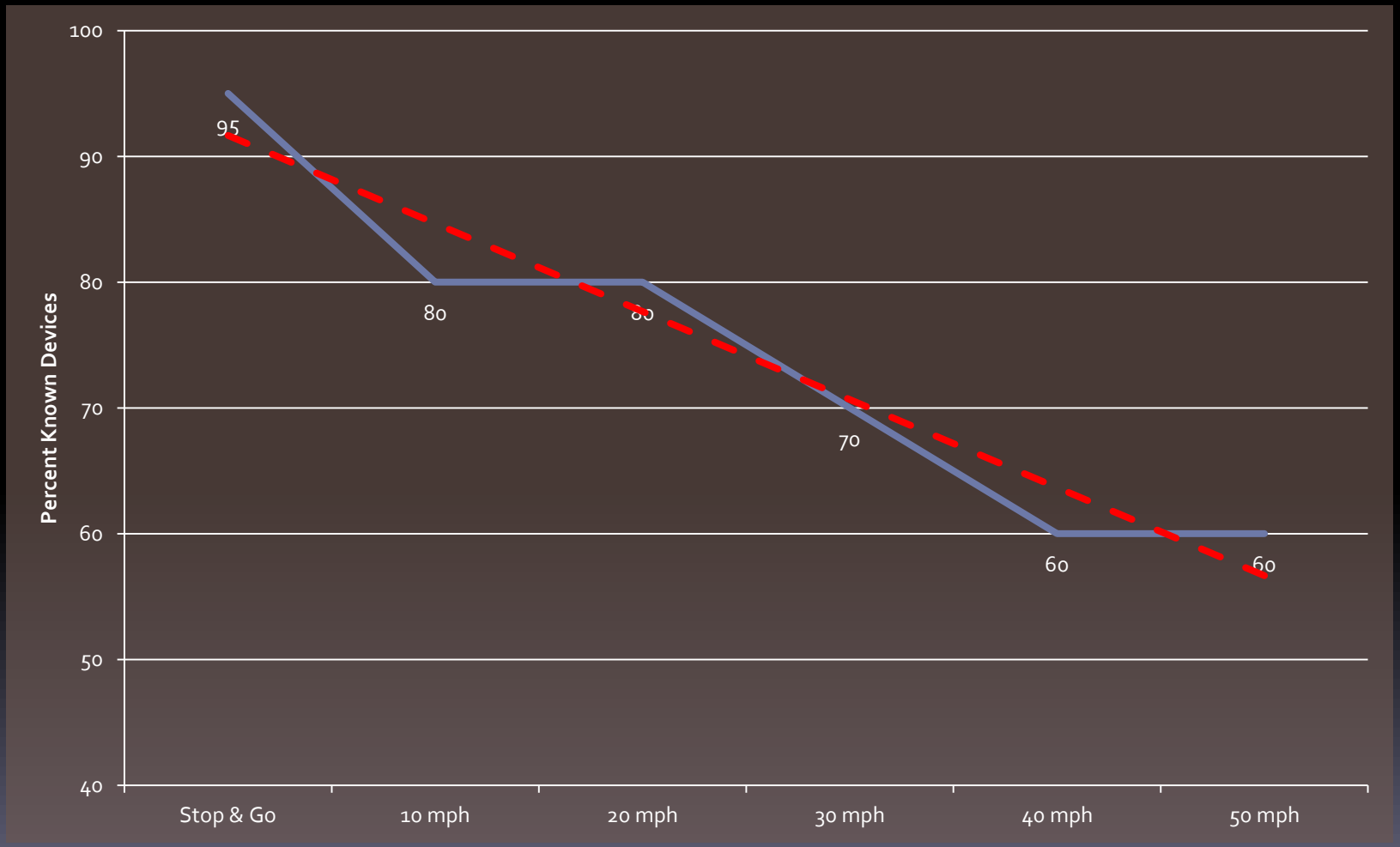
Device Read Conclusions

- No trending of individual devices was seen
- Number of reads per device did not necessarily decrease at higher speeds
  - Remember each scan reports devices multiple times, while in range
  - The number of reads for individual devices were often the same at higher speeds

Percent Devices Detected

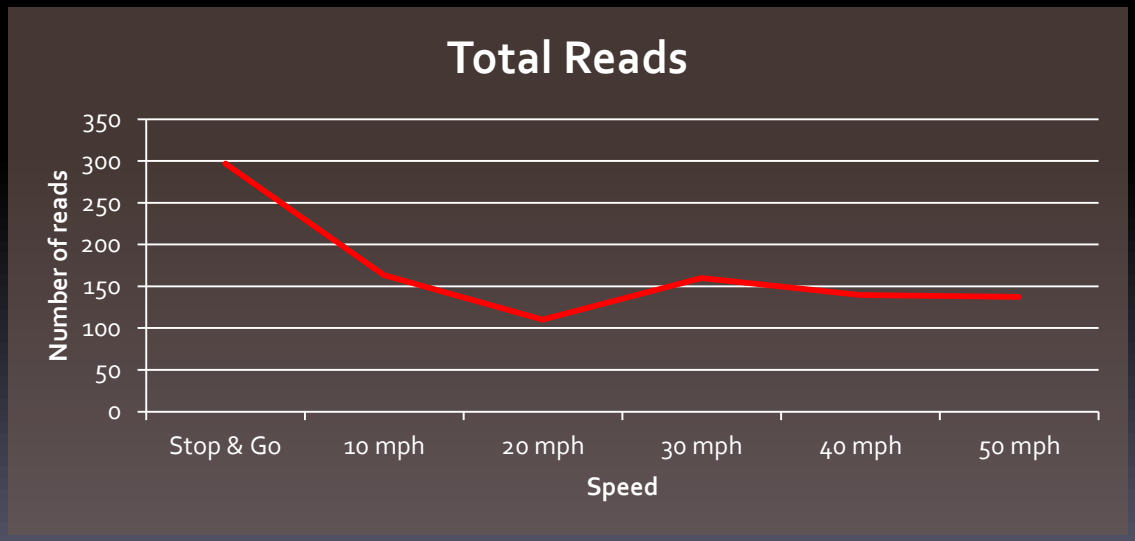
- Since testing with a number of known devices, data was collected for which devices were detected at varying speeds
- Stop and go conditions, as expected, found all known devices for each scan
- At higher speeds, fewer known devices were located—also as expected
- Trending was linear

Percent Devices at Various Speeds



Speed Related Conclusions

- Sufficient percentage of devices can be found even at higher speeds
- Large numbers of reads per device even at higher speeds—ranged from 88 to 176 at 50 mph

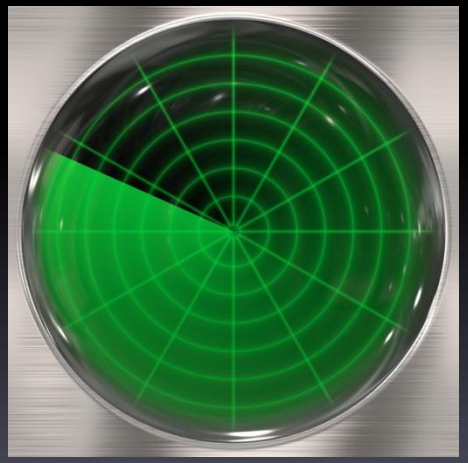


What Questions Were We Asking?

- Can scans be performed fast enough for highway speeds to be calculated?
- Can temperature rated equipment be assembled to create roadside-ready hardware?
- What about end user devices?
  - Are there enough to provide valid times?
  - Must the devices be in discoverable mode?
- What type of antennae are required for highway testing?

And the Answers? Question 1

- Can scans be performed fast enough for highway speeds to be calculated? **Yes**
  - Scanning process was 10-12 seconds, returning multiple scans per device at each speed tested



Answer: Question 2

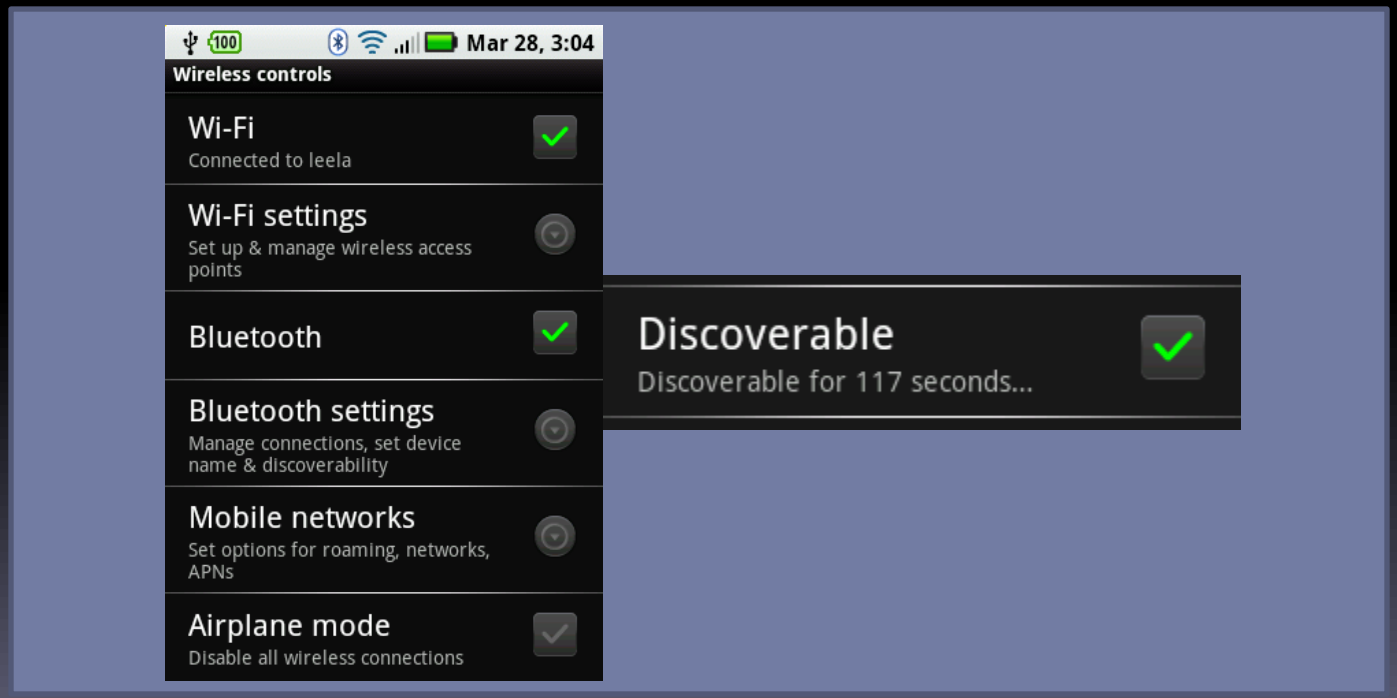
- Can temperature rated equipment be assembled to create roadside-ready hardware? **Yes**
  - Micro controllers
  - Bluetooth adapter by Parani
    - Other manufacturers will provide prices for temperature hardened
    - Chips also exist
  - Multiple antennae exist, if required

And the Answers? Question 3

- What about end user devices? Are there enough to provide valid times?
  - The answer to that question is "it depends"
  - As recently as 1year ago, Bluetooth travel times devices were reporting 3-10% penetration rates
  - Remember there was a part two to that question?

Answer: Question 3, Part 2

- Part two: Must the devices be in discoverable mode?
  - Ah, here lies a potential problem for the future of this technology…



Discoverable Mode

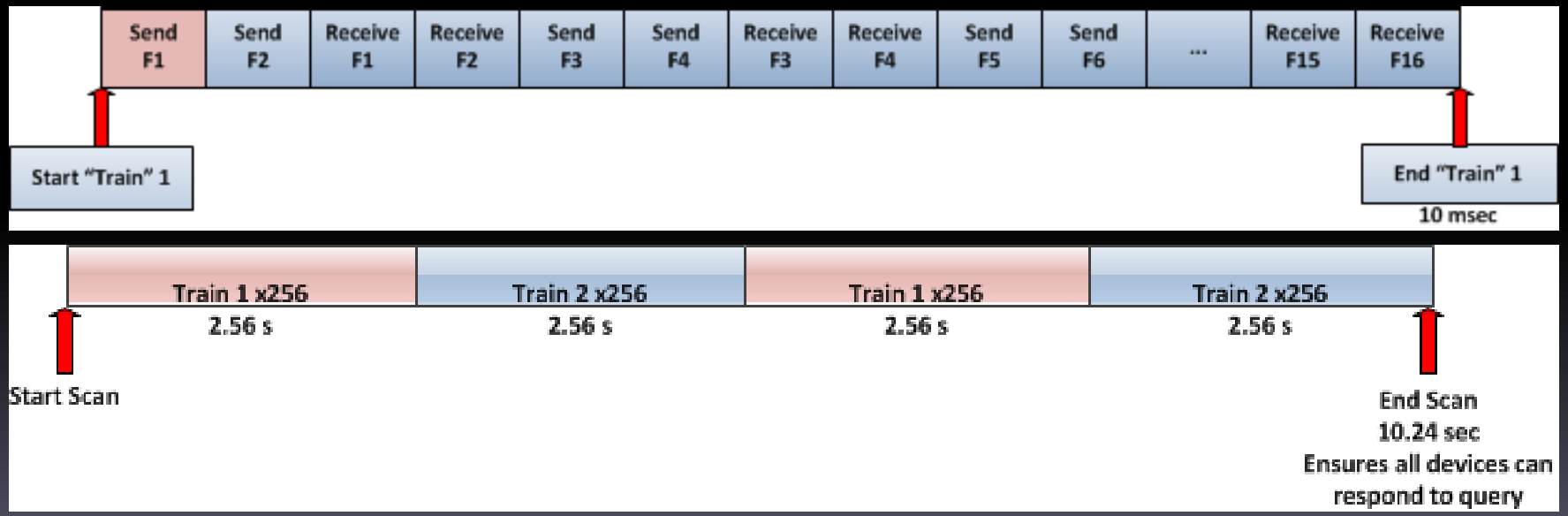
- End user devices such as cell phones were previously in Bluetooth "discovery mode" by default
  - Allows pairing with headsets
  - Allows your laptop to connect to a mouse or other device
- More recently?
  - Devices can be placed in discoverable mode for a limited time
  - Once pairing with a device occurs, there's no reason to stay in discoverable mode

Can We Find Non-Discoverable Devices?

- Sure we can—if we are willing to wait a week or two
  - To "find" a device not in discoverable mode, we have to query it by its MAC address
  - We can use brute force to go thru the entire range of MAC addresses until it answers
    - We can even limit the range to only cell phone manufacturers
  - Scanning the range can take over a week using **79** distinct adapters to query each of the Bluetooth frequencies
  - With 1 adapter? One study calculated scanning would take **1.4 years**!

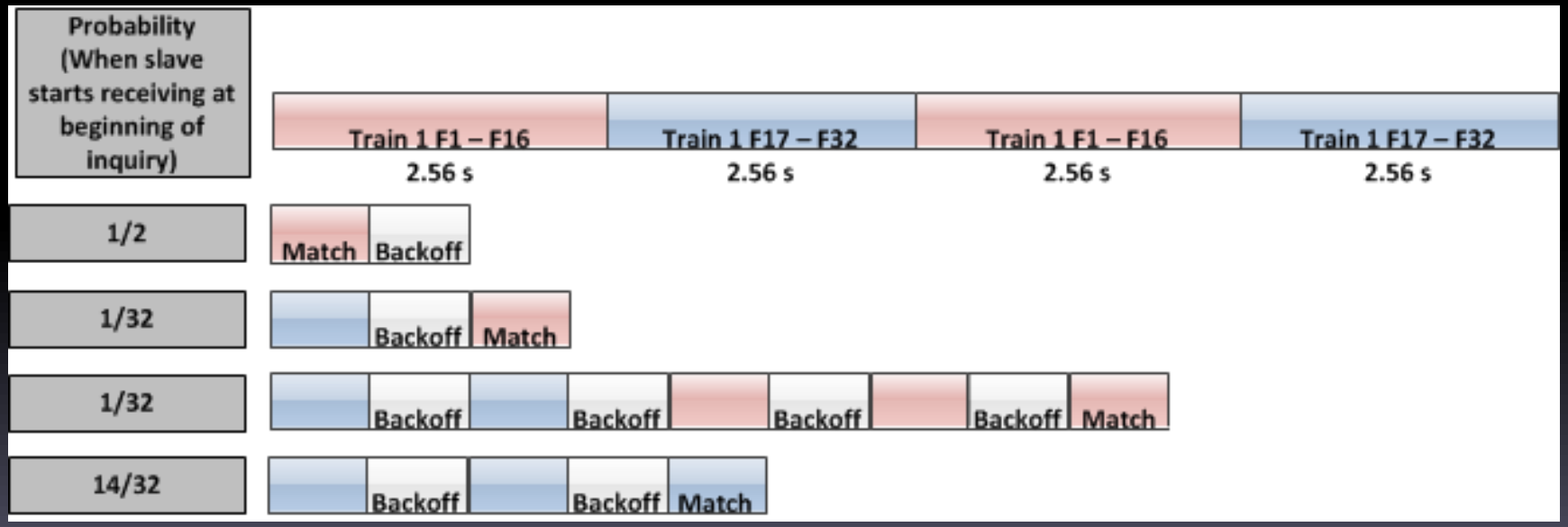
Discovery Frequency Hopping

- One of the reasons for extensive search time
- Out of 79 frequencies used during Bluetooth communication, only 32 used in discovery



One Discovery Example

- Each depends on when the slave starts receiving
- Seven other cases shifted slightly



Does It Matter?

- There are plenty of devices out there in discoverable mode, does it matter that we cannot find the others?
  - Not this year, and probably not next year
  - Five years from now, this may matter quite a bit
- Cell phone manufacturers have been limiting discoverable mode on devices
  - Newer phones can be placed in discoverable mode for a limited time
  - Most CANNOT be left in discoverable mode

Agenda

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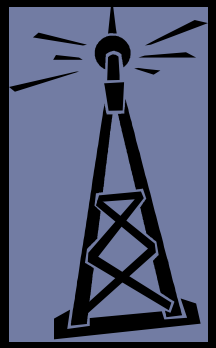
So, What Does This Mean?

- Bluetooth technology is still viable short term
- Would recommend several test units placed in conjunction with existing "known" detection devices
  - Can track the trending over time for volume of reads/matches
  - Comparing against known detection source gives a good comparison

Protect Against Obsolescence



- Process matching and calculations at a central location—one process can support multiple technologies
- Pure "tag reading" can be swapped out for new technology as it appears
  - Dedicated Short Range Communication (DSRC) radios
  - Cell phone signals
  - Something currently unknown (who knew of Bluetooth for this usage 10 years ago!)

Six Months Later

- TxDOT has test devices along I-35 where radar detection exists
  - Seeing 1% penetration rates compared to radar volumes
  - Often only one tag read per 20 second cycle
  - Only one manufacturer, attempting to determine if this is a problem with the devices
- With our test system, visited same location initial testing occurred
  - Received 1/2 the number of reads

Newer Bluetooth Versions

- 3.0 + HS
  - After connecting, high speed transmission occurs over 802.11
- 4.0 (Bluetooth smart)
  - Lower power consumption for short bursts
    - *Possibly* may result in discoverable mode staying on
    - Given privacy concerns, not likely
  - Less range (50 m for class 1 devices)
  - Not backward compatible, but may be dual mode
  - Used by Apple in new products
    - Discoverable only when in the Bluetooth settings

Questions?

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