Master's Thesis Defense

# An empirical study of user-perceived interoperability of Bluetooth devices

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# Introduction

- Overview of Bluetooth
- Interoperability: Key factor affecting Bluetooth
- Bluetooth interoperability problem
- Study of interoperability
- User-perceived approach to assessment
- Test strategy and experimental approach
- Results and analysis
- Conclusion

# Overview of Bluetooth

- *Bluetooth* is a short range wireless technology
  - Main idea: Cable replacement
  - Range: 10~100 meters – data rate up to 3 mbps
  - High market penetration: 670 million devices expected to be shipped by 2005
- How is Bluetooth unique?
  - Widespread use cases – unlike other technologies
  - Mobile phones, headsets, PDAs, PCs, HIDs, GPS receivers, high-quality audio streaming applications
  - Multiple use cases exist within a given set of devices

# Interoperability

- *Interoperability* is the condition achieved when two or more technical systems exchange information directly in a way that is satisfactory to the users of the systems.
- Bluetooth Special Interest Group
  - Trade association formed by group of leading companies
  - Promotes Bluetooth technology
  - Develops and maintains the specifications
  - Administers the Qualification program
    - Test Bluetooth devices and ensure interoperability

# Background

- Interoperability is the key factor for success of Bluetooth
- There is a popular notion among the user community that Bluetooth devices in the market interoperate poorly
- Problems are mostly unknown and not studied
- We take the user's perspective in studying the nature of problems
- Our results show that problems stem from various areas
  - Lack of stringency in specification and inadequate qualification testing contribute to some problems
  - Low-level, high-level and user-level problems contribute to interoperability failures

# Goals

- What is the state of Bluetooth from a user's perspective?
  - What is the nature of problems Bluetooth suffers from?
    - What steps can be taken in order to improve the state of Bluetooth?

# The Approach

- Received 37 devices from Bluetooth SIG
- Devices are from different categories
  - Mobile phones (MP)
  - Headset devices (HS)
  - Handhelds (HH)
  - Personal Computers (PC)
  - GPS, Imaging device, Human interface devices, access points
- Develop user-oriented interoperability test cases
- Form default expectation of features
- Perform tests on several device pairs
- Analyze results and derive conclusions

# Choosing the interoperability tasks

- What activities constitute “normal interoperability tasks”?
  - Numerous possible tasks for a given pair
  - Commonly used tasks selected based on best judgment
  - Feasibility to complete tests and analyze results
- Limit focus to 4 major device categories
  - MP, HS, HH and PC
  - They constitute 90% market share
  - 9 unique device type pairs possible

# Expected Features / Interoperability

| Devices/ Capabilities | **Personal Item Transfer** | **Dial-up Network-ing** | **Fax** | **File Sharing** | **LAN Access** | **Audio/ Play Music** | **Audio/ Call handling** |
|---|---|---|---|---|---|---|---|
| Mobile Phones (MP) | Yes | Yes | Yes | | | | Yes |
| Headset Devices (HS) | | | | | | Yes | Yes |
| Handheld Devices (HH) | Yes | Yes | | Yes | Yes | Yes | |
| Personal Computers (PC) | Yes | Yes | Yes | Yes | Yes | Yes | |

# Test Cases

- Business card exchange
- Transfer address book entry
- Transfer calendar entry
- Transfer a picture
- Transfer a voice memo
- Synchronize data
- LAN access
- Dial-up networking
- Send/receive FAX
- Play music using headset
- Headset as a Mobile phone accessory
  - Answer an incoming call using headset, mobile phone
  - Initiate a call using headset, mobile phone
  - Transfer a call between headset and mobile phone

# Sample test cases

1. Business card exchange
   - **Test Purpose:** To test the ability of two devices to exchange business cards.
   - **Pass Criteria:** Device A must initiate the exchange with device B, device A shall receive device B's business card with all the original information unaltered, vice versa.

2. Synchronize data
   - **Test Purpose:** To test the ability of a device pair to synchronize selected data.
   - **Pass Criteria:** Device A initiates the synchronization, and as a result all calendar entries and contacts selected for the process must be synchronized between device A and device B. No action needed on device B.

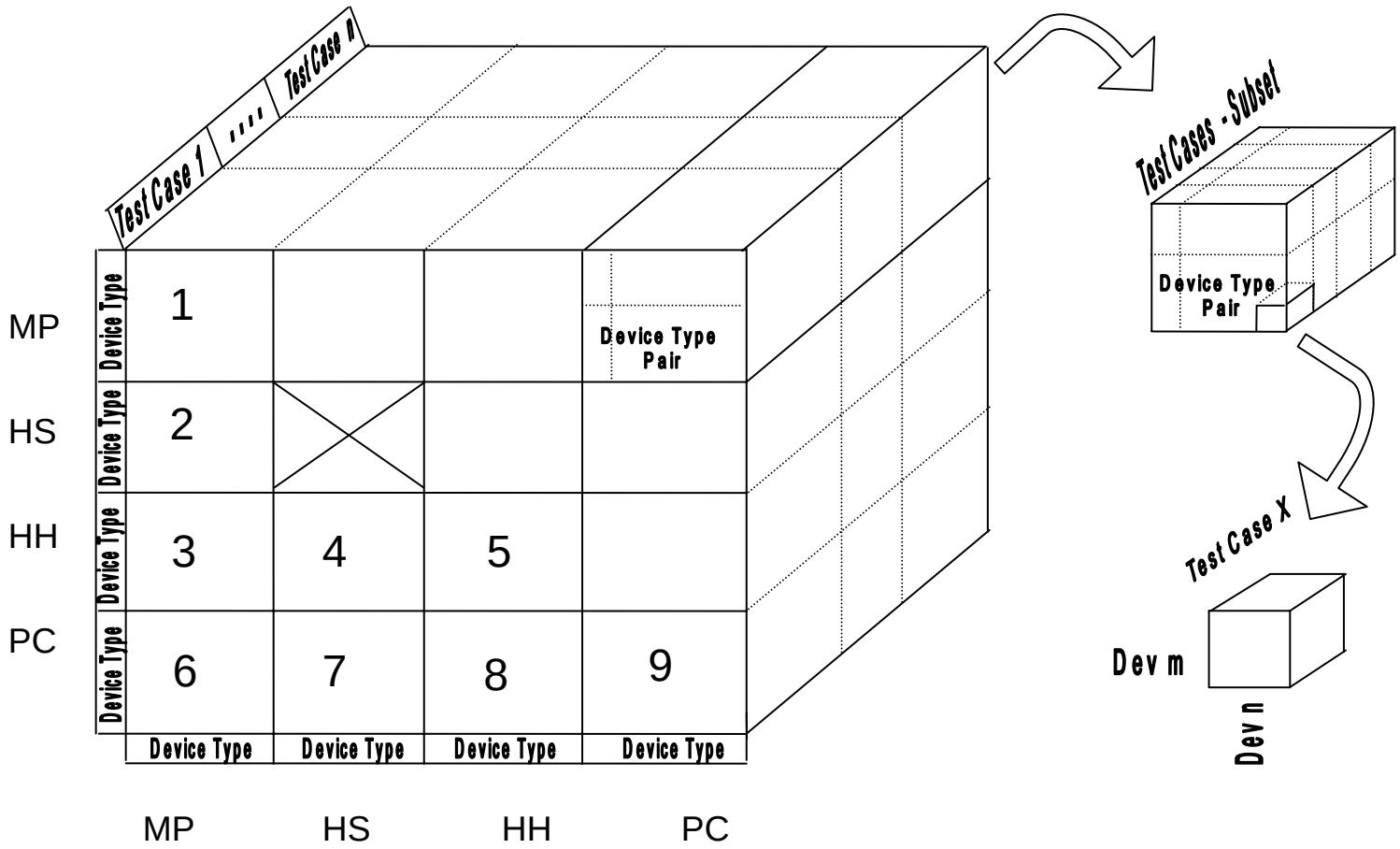
Note : Test cases also contain **Initial conditions**, step by step **procedure**, and **fail verdict criteria**, associated with them.

# Test Case Mapping / Applicability

- (HH, MP) test cases
  - Business card exchange
  - Transfer address book entry
  - Transfer calendar entry
  - Transfer a picture
  - Dial-up networking
  - Transfer a voice memo
  - Send/receive FAX
  - Synchronize data
- Similar mapping exists for other 8 device type pairs

# Device type pair matrix

9 device type pairs



# Statistics on amount of testing

- 30 devices tested
  - 5 handheld devices
  - 8 mobile phones
  - 11 headsets
  - 6 personal computers

2 combinational devices (Mobile phone and PDA device such as a Smart Phone)
-The super set of tests apply for those devices

## Possible

- 9 device type pairings
- 559 individual device pairs
- 2979 total possible test cases

## Actual

- 9 device type pairings
- 325 pairs
- 1745 test cases

# Test Suite Highlights

- General purpose user-oriented test cases
- Re-usable for newer Bluetooth devices
- Based on simple user expectations
- Easy to understand for ordinary users
- Test cases have Purpose, Procedure, Pass and Fail verdicts
- Product user manual referenced as needed
- Detailed guidelines for performing tests

# Metrics of Interoperability

- The verdict
  - Pass or Fail decision
- Failure type
  - in case of failure
- Errors
  - Temporary failures
- Subjective scale
  - measure of difficulty in achieving success
- Time taken to complete the task
- Operator notes – extra information

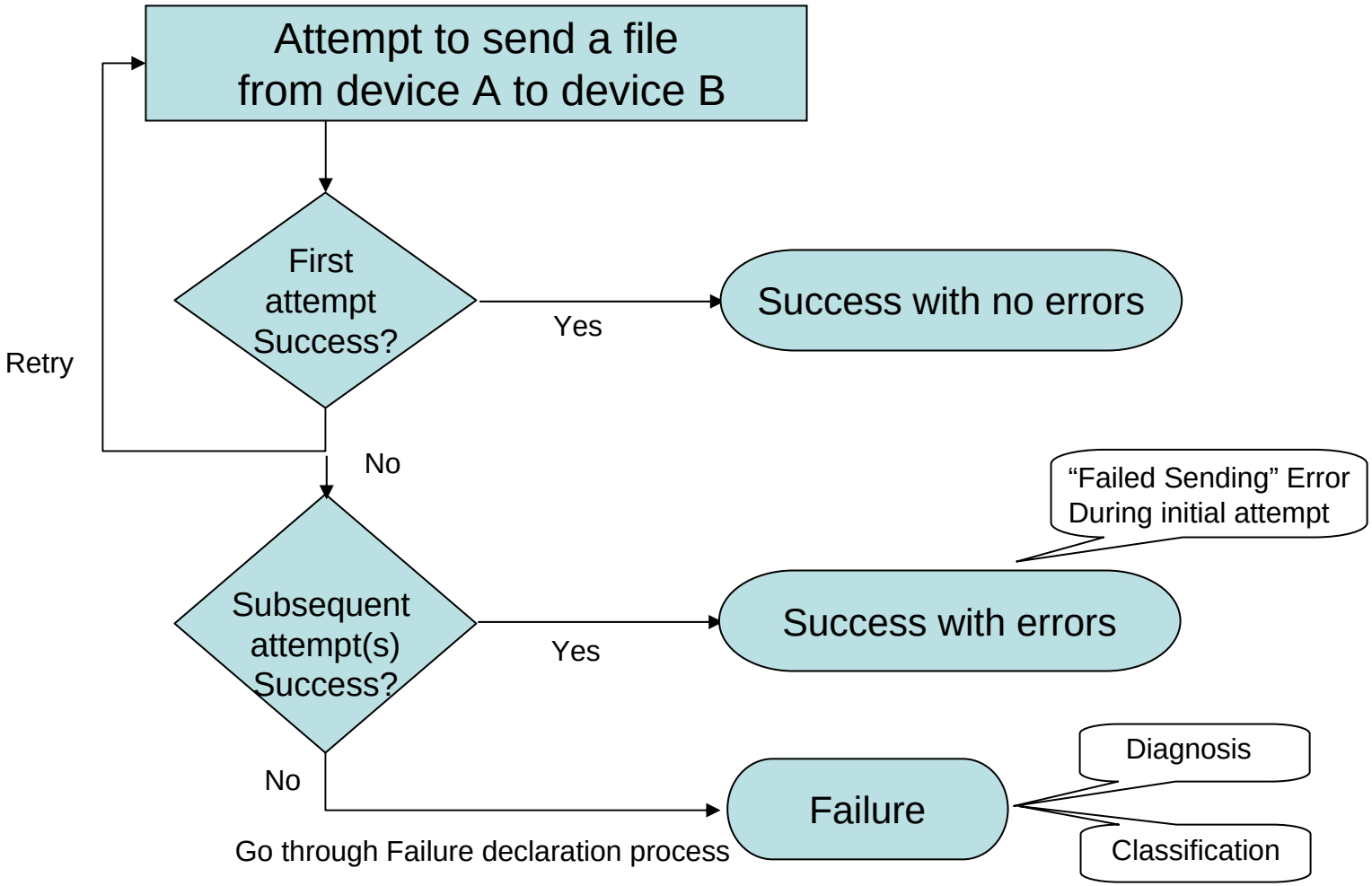
# Success / Failure

- A failure is declared when we cannot achieve the test purpose with reasonable effort
- Failure due to Bluetooth issues
  - Assumes devices have matching features based on qualification information
  - Different types – discussed later
- User-level failure
  - Expectation not met
  - Wrong claim – user manual, packaging, media
- Unqualified Success
  - Desired task achievable without problems – Pass verdict is assigned
- Qualified success
  - Considerable time and effort needed to achieve the purpose, temporary failures observed
  - Subjective scale data helps in classifying success

# Errors

- *Errors* are temporary failures
  - Example: Unable to detect device during search process, but the device was found in the second or subsequent attempts
- Error data is a measure of probability of occurrence of interoperability-issues in devices
- Errors are viewed in two ways
  - Average Error
    - Ratio of total number of errors and total number of test cases
  - Error Rate
    - Ratio or number of test cases with at least one error
- Correlation analysis of error data is likely to reveal low-level issues

# Overview of Verdict Assignment



# Results and Analysis

- Results from testing is analyzed in different ways
- Failures are important interoperability measures
- Based on need, result data can be grouped or segregated to give broader or narrower perspective
- Three different views are considered to be of interest
  1. Viewing results by device type pairs
  2. Viewing results by Test cases
  3. Viewing results by Failure types

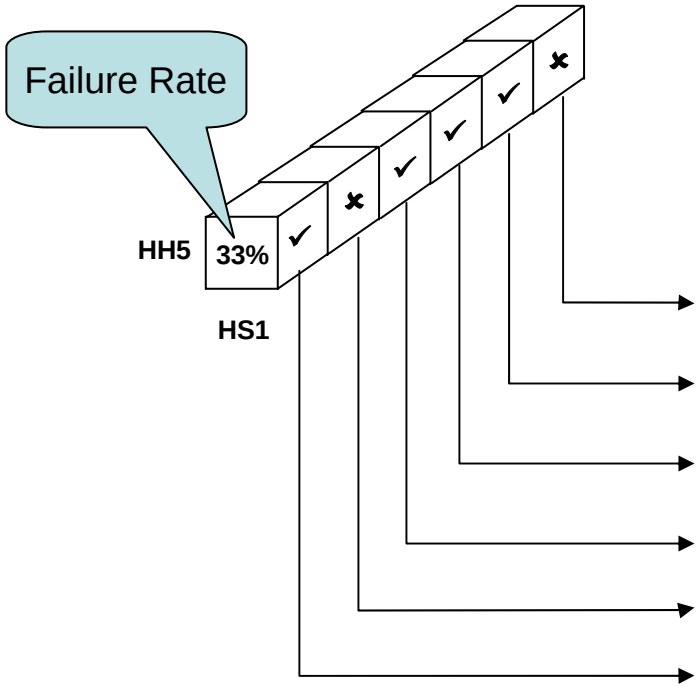
# Mobile Phone Headsets Failure Rates

Results of one device type pair across multiple test cases

| | HS1 | HS2 | HS3 | HS4 | HS5 | HS6 | HS7 | HS8 | HS9 | HS10 | HS11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| HH5 | 33% | 33% | 83% | 33% | 33% | 33% | 33% | 33% | 33% | 33% | 33% |
| MP1 | 17% | 17% | 17% | 17% | 17% | 17% | 17% | 17% | 17% | 17% | 17% |
| MP2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| MP3 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| MP4 | 0% | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | 0% | 0% | 0% | 0% |
| MP6 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| MP7 | 0% | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | 0% | 0% | 0% | 0% |
| MP8 | 0% | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | 0% | 0% | 0% | 20% |

# One device-pair result

An individual smart phone – headset pair




6 Test Cases

**Play a recorded audio sample**

**Transfer call between headset and mobile phone.**

**Receive a call using a headset and talk through the headset**

**Receive a call using the phone and talk through the headset**

**Initiate call from headset and talk through mobile phone**

**Initiate call from mobile and talk through headset.**

**✓ - Success**

**✗ - Failure**

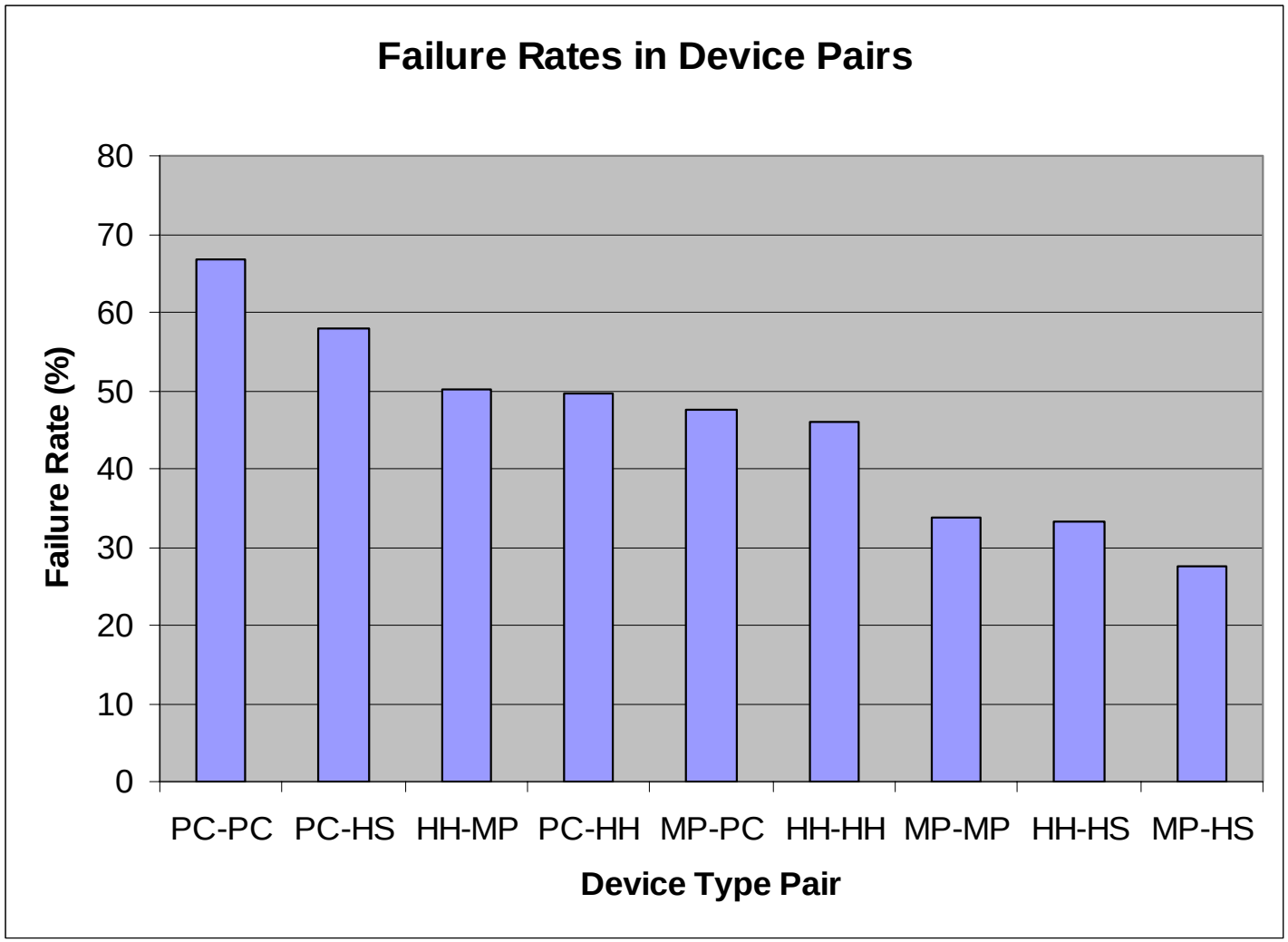
Smart phone is a mobile phone with PDA capabilities

# Failures in Device Pairs

Summary of 9 device type pairs and their failure rates

| Type-Pair | Number of pairs | Number of Test cases | Number of Failures | Failure Rate% |
|---|---|---|---|---|
| MP-HS | 88 | 462 | 127 | **27.5** |
| HH-HS | 34 | 144 | 48 | **33.3** |
| MP-MP | 66 | 362 | 121 | **33.7** |
| HH-HH | 21 | 122 | 56 | **45.9** |
| MP-PC | 38 | 257 | 122 | **47.5** |
| PC-HH | 16 | 99 | 49 | **49.5** |
| HH-MP | 74 | 471 | 236 | **50.1** |
| PC-HS | 19 | 19 | 11 | **57.9** |
| PC-PC | 30 | 192 | 128 | **66.7** |

# Failures in Device Pairs



# Failures by Test Cases

## Transfer calendar entry - Pass/Fail data

### -Multiple device types and one test case

| 0 | HH1 | HH2 | HH3 | HH4 | HH5 | MP1 | MP2 | MP3 | MP4 | MP5 | MP6 | MP7 | MP8 | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HH1 | x | USF | x | UFF | UDB | UFF | UDB | UDB | UFF | x | UFF | FS | x | x | x | x | UDB | UFF | UFF |
| HH2 | UFF | x | t&d | 0 | t&d | t&d | 0 | 0 | 0 | 0 | 0 | 0 | t&d | x | x | x | x | 0 | USF |
| HH3 | x | 0 | x | FS | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| HH4 | FS | 0 | t&d | x | t&d | t&d | 0 | t&d | t&d | t&d | 0 | 0 | t&d | x | 0 | x | x | x | x |
| HH5 | PNI | 0 | x | 0 | x | x | 0 | FS | UFF | UFF | FS | UFF | 0 | x | 0 | x | x | x | x |
| MP1 | UDB | 0 | x | 0 | x | x | 0 | 0 | 0 | 0 | 0 | x | x | x | 0 | x | x | x | x |
| MP2 | UFF | 0 | x | t&d | 0 | 0 | x | 0 | 0 | 0 | 0 | 0 | 0 | FS | UFF | x | x | x | x |
| MP3 | UDB | 0 | x | t&d | t&d | 0 | 0 | x | 0 | 0 | 0 | 0 | 0 | FS | 0 | x | x | x | x |
| MP4 | UDB | 0 | x | t&d | 0 | 0 | 0 | 0 | x | 0 | 0 | 0 | 0 | FS | 0 | x | x | x | x |
| MP5 | x | t&d | x | 0 | 0 | 0 | UFF | 0 | 0 | x | 0 | 0 | 0 | x | x | x | 0 | 0 | FS |
| MP6 | USF | 0 | x | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | 0 | 0 | FS | 0 | x | x | x | x |
| MP7 | MBC | 0 | x | 0 | 0 | x | 0 | 0 | 0 | 0 | 0 | x | 0 | x | x | x | 0 | 0 | DL |
| MP8 | x | 0 | x | 0 | 0 | x | 0 | 0 | 0 | 0 | 0 | 0 | x | x | x | x | 0 | 0 | FS |
| PC1 | x | x | x | x | x | x | 0 | 0 | t&d | x | 0 | x | x | x | 0 | UDB | UDB | 0 | 0 |
| PC2 | x | x | x | FS | 0 | UFF | UFF | FS | UFF | x | FS | x | x | FS | x | USF | FS | FS | FS |
| PC3 | x | x | x | x | x | x | x | x | x | x | x | x | x | USF | USF | x | UDB | USF | USF |
| PC4 | FS | x | x | x | x | x | x | x | x | 0 | x | 0 | t&d | 0 | FS | FS | x | 0 | 0 |
| PC5 | UFF | 0 | x | x | x | x | x | x | x | 0 | x | 0 | 0 | FS | FS | UDB | 0 | x | 0 |
| PC6 | FS | 0 | x | x | x | x | x | x | x | 0 | x | t&d | 0 | FS | 0 | USF | 0 | 0 | x |

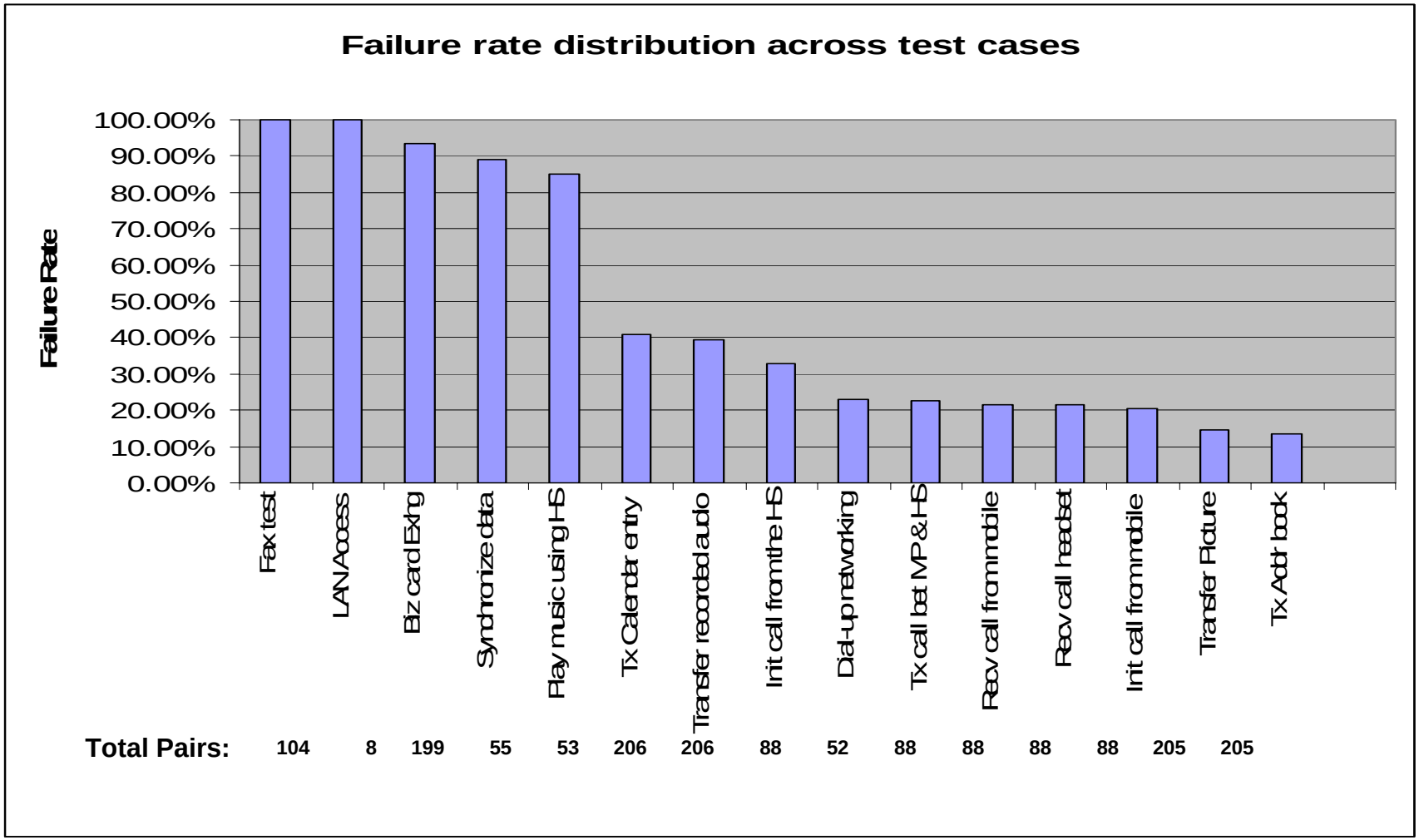
| | |
|---|---|
| type | **Failure** |
| 0 | **Success** |
| x | **Not tested** |

# Transfer Calendar Entry Failure Breakdowns

| Type ID | Total Failures | % Type | Type of Failure |
|---|---|---|---|
| FS | 25 | 30% | "Failed sending" error |
| t&d | 19 | 23% | Transferred calendar times/dates are incorrect |
| UFF | 17 | 20% | Unsupported file format |
| UDB | 11 | 13% | Unable to detect device during Bluetooth Search |
| USF | 9 | 11% | Device pair does not support feature under test. |
| MBC | 1 | 1% | "Max number of Bluetooth connections…" error |
| DL | 1 | 1% | Data lost while transferring |
| PNI | 1 | 1% | Pairing cannot be initiated from device |
| All | 84 | 41% | Total number of failures / Failure rate % |

- 84 out of 206 pairs of devices experienced failures in this test case.
- This represents 41% failure rate, and over 11% share of 745 total failures recorded.

# Failure rate distribution across test cases



# Failure Types

- Pairing cannot be initiated from device
- "Failed sending"
- "Unable to connect…"
- "Max number of Bluetooth connections…"
- Unable to detect device during Bluetooth search
- Pairing Error: "Unable to Pair…"
- "Profile not supported…"
- Device pair does not support feature under test.
- Unsupported file format
- Transferred calendar times/dates are incorrect
- Data lost while transferring

# Failure declaration process

Step by step process in which the fail verdict of a test case is assigned

- The failed test step is repeated
- The entire test case is repeated after resetting the devices to their initial condition
- Proper battery charge is ensured and the devices are power cycled
- User manual is looked up to check whether operation is carried out as instructed
- Latest online resource (if any) is used to find additional help
- A different test operator attempts to perform the test
- The devices are set in a different environment and the test case is repeated
- The manufacturer's technical support department is called for professional help

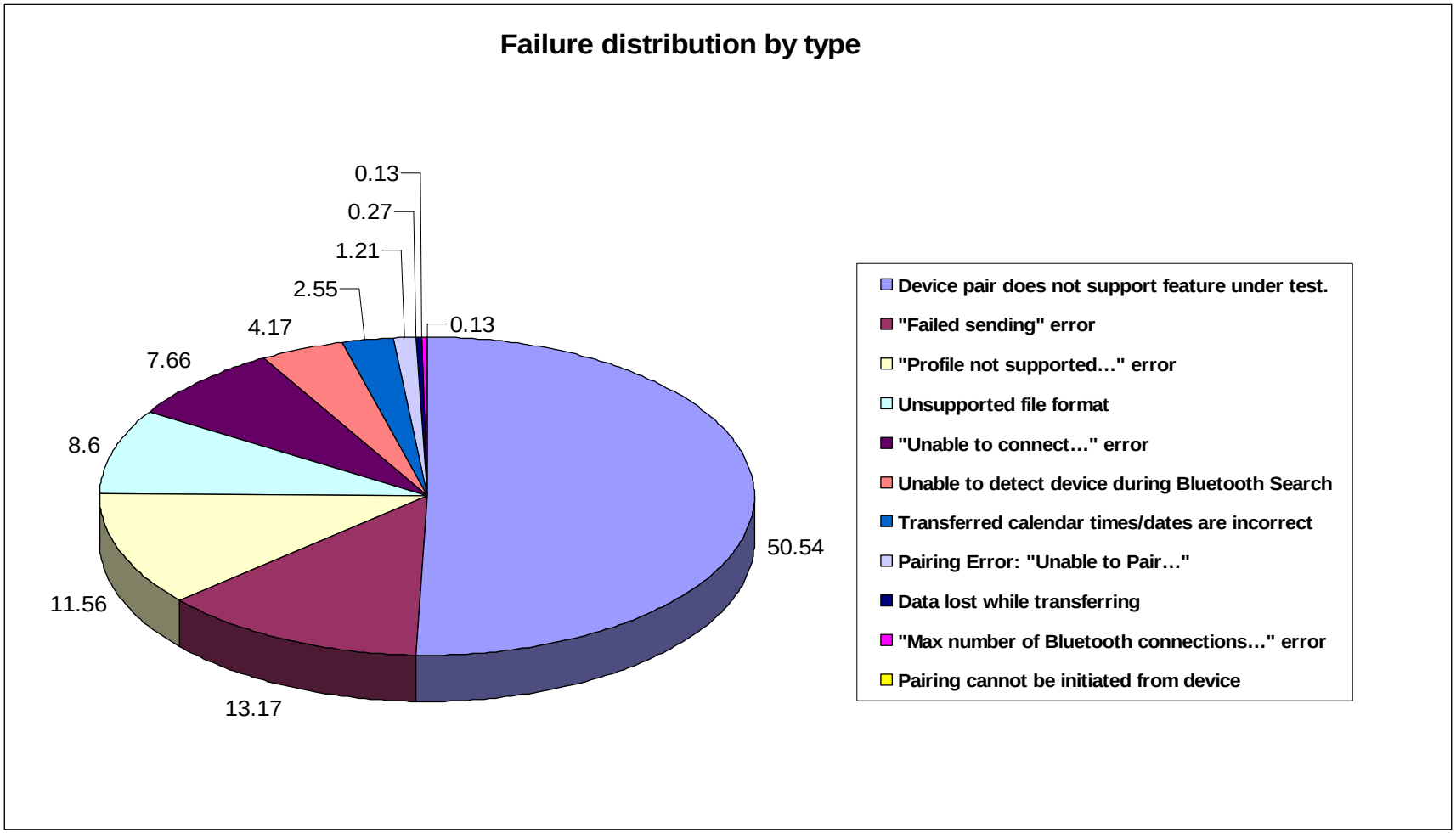
# Overall summary of failures

| Broader issue* | Total | % of Total | Failure Description |
|---|---|---|---|
| User Level | 376 | 50.54 | Device pair does not support feature under test. |
| Lower Level | 98 | 13.17 | "Failed sending" error |
| User Level | 86 | 11.56 | "Profile not supported…" error |
| User Level | 64 | 8.60 | Unsupported file format |
| Lower Level | 57 | 7.66 | "Unable to connect…" error |
| Lower Level | 31 | 4.17 | Unable to detect device during Bluetooth Search |
| Higher Level | 19 | 2.55 | Transferred calendar times/dates are incorrect |
| Lower Level | 9 | 1.21 | Pairing Error: "Unable to Pair…" |
| Higher Level | 2 | 0.27 | Data lost while transferring |
| Lower Level | 1 | 0.13 | "Max number of Bluetooth connections…" error |
| Lower Level | 1 | 0.13 | Pairing cannot be initiated from device |

**744** Failures out of **1745** total test cases indicating **42.6%** overall failure rate

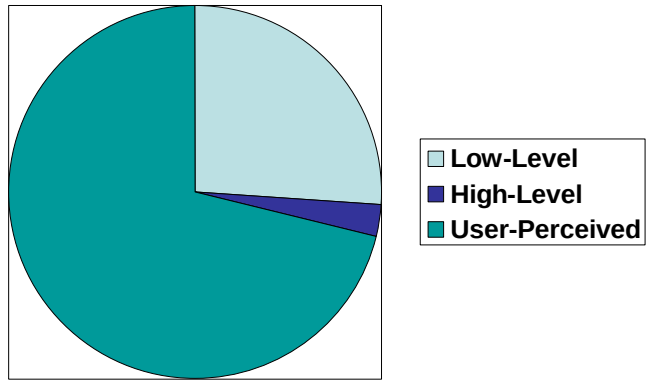
Note: ***Some issues may fall under multiple categories E.g. Higher level & User perceived

# Failure distribution by type



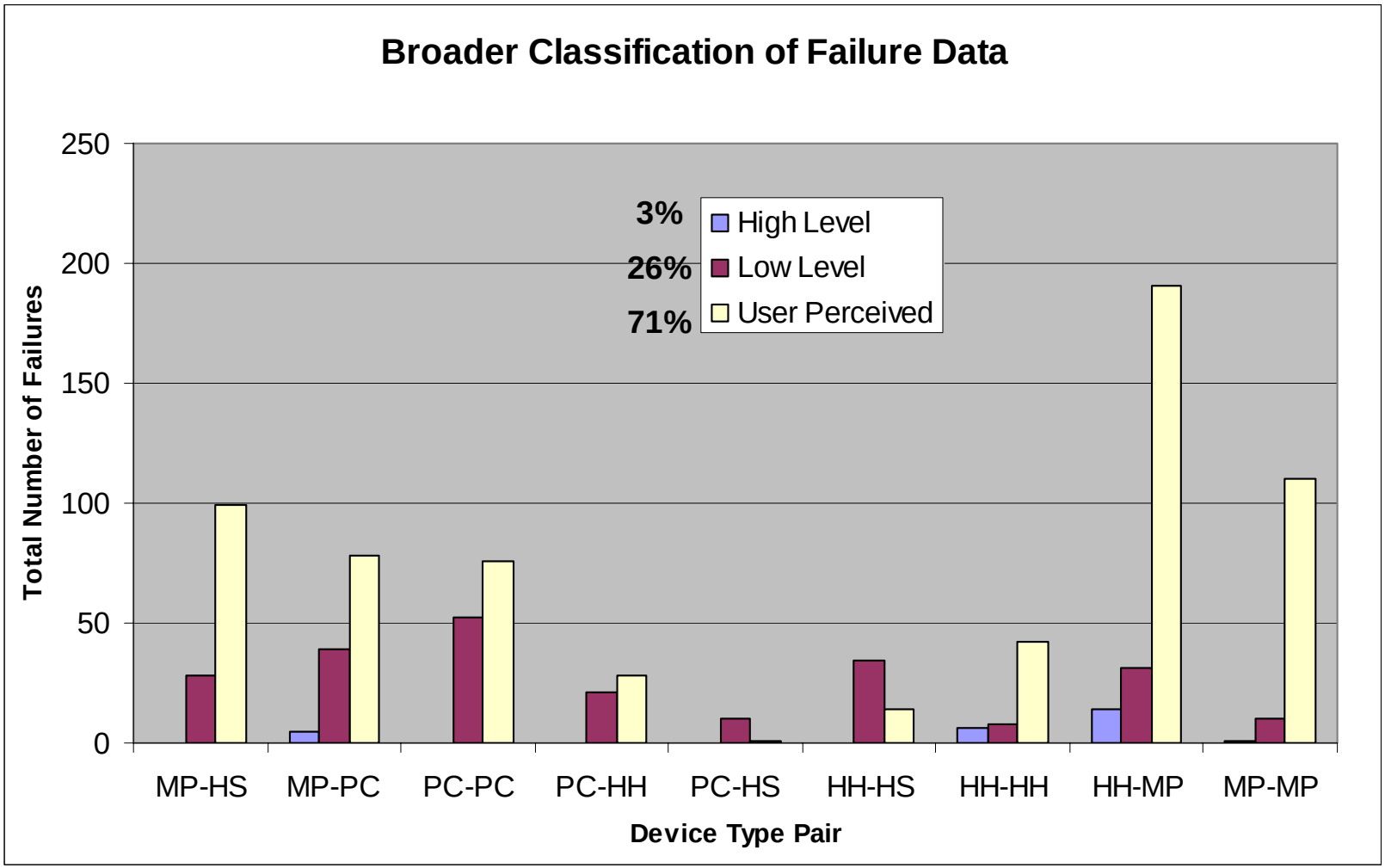
# Classification of Failure types

| | |
|---|---|
| High Level | **Transferred calendar times/dates are incorrect** |
| High Level | **Data lost while transferring** |
| Low Level | **"Failed sending" error** |
| Low Level | **"Unable to connect…" error** |
| Low Level | **Unable to detect device during Bluetooth Search** |
| Low Level | **Pairing Error: "Unable to Pair…"** |
| Low Level | **"Max number of Bluetooth connections…" error** |
| Low Level | **Pairing cannot be initiated from device** |
| User Level | **Device pair does not support feature under test.** |
| User Level | **"Profile not supported…" error** |
| User Level | **Unsupported file format** |




| Percentage | Number of failures | Categorization of Issues |
|---|---|---|
| 26% | 197 | Low-Level Bluetooth Issues |
| 3% | 21 | High-Level Bluetooth Issues |
| 71% | 526 | User-Level Issues |

# Border Classification of failure data



# Conclusion

- Overall failure rate of 42% is alarming
- Nearly half of the observed failures are due to incompatible features
- Interoperability problems are scattered and reasons are widespread
- There are easy solutions to many problems
- Managing user expectations is the key to improve interoperability
- Only 25% of all the failures may be due to low-level Bluetooth issues [good news]

# Limitations/Critique

- Higher level classifications of failures may not be accurate. Failure diagnosis process will help in better classification.
- Choice of test cases were based on our judgment. Market analysis will help solving this issue.
- Results could be given weights based on relative “importance” of test cases
- Other collected test data such as time and subjective scale is not used during analysis
- Lack of availability of a data base management tool affected the analysis and testing process by increasing the time requirements

# Future Work

- Tracking down and analyzing root cause of identified problems
  - Failure diagnosis requires considerable effort, but adds value
- Extend testing with
  - Newer devices against old devices
  - Other device categories
  - More use cases, preferably after market survey of user expectations with Bluetooth
- Develop a database management tool to aid testing: Ongoing
- Identify test cases to include in existing Bluetooth qualification program
- Come up with a set of feature recommendations based on market survey data
  - Adds a lot of value to technology

# Questions?

THANK YOU