Evaluating the Performance of Smartphones Scanning for Low Energy Beacons

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***Abstract*— Smartphones are now regularly used to scan for the presence of beacons. The information received by the scanner can be displayed or used to start other processes. It happens that smartphones fail to find beacons, although they are advertising. There are several reasons for that failure. A major one is the scanning behaviour of the smartphone. We designed and implemented ways of testing the performance of smartphones while they scan for Bluetooth Smart beacons or for low-power sensors. We used the tests to determine important tuning parameters. We also used the tests to compare a number of popular smartphones and verify the effect of parameter adjustments on their performances.**

Keywords—Beacon; Smartphone; Bluetooth Smart; Scanner; Low power; Energy Harvesting;

I. INTRODUCTION AND MOTIVATION

Smartphones are used in many applications to scan for the presence of beacons or other Bluetooth Smart sensors. In some cases, the information received by the scanner is used directly. For instance, measurements that are shown directly on the display (Fig. 2). In other cases, the data from the beacons is passed on and used to start other processes (Fig. 1, Fig. 3). This might be the case in proximity marketing where customers are attracted using beacon technology [1]. Whatever the end use is, smartphones and beacons based on the Bluetooth wireless technology are key elements in that chain.

Beacons are small devices that continually transmit information using specific wireless channels, based on the Bluetooth protocol. They are designed to be low cost and minimise energy consumption. They may be attached to an object or simply placed at a given location to send the required information. Some variations are used to make measurements that can be read using the smartphones (Fig. 2).

Smartphones are popular and user-friendly platforms, equipped with the necessary wireless, computing and user-interface resources. There are several variations on the market, performing differently. The utilisation of smartphones as scanners for Bluetooth Smart beacons has some limits. The reliability in detecting and receiving frames differs from smartphone to smartphone. In extreme cases, some beacons might not be seen or might only be seen after a long time, although they do advertise. Low-power devices that cannot afford to advertise very often are especially affected. This situation can have negative consequences on user experience, energy requirements, development resources and product acceptability. In this work, we designed and implemented ways of testing the performance of smartphones when they scan for Bluetooth Smart beacons or low-power sensors. We used the tests to determine important tuning parameters. We compared a number of smartphones that are on the market and verified the effect of parameter adjustments on the scanning performance.

A key aspect that affect advertisers and scanner is energy consumption. Devices that transmit or receive need a fair amount of energy and manufacturers are keen on reducing power consumption.

Having many sensors of small size means that one wants to avoid (or at least seriously limit) battery replacement. Consequently, devices are designed to use a very small amount of energy. Reduction of energy requirement can be achieved by several methods [2]:

- Choosing devices with low energy consumption is the first step. This means paying attention to the behaviour of the wireless embedded system in transmission, reception and sleep modes.
- Using duty-cycling techniques. It means that the device transmits for a very short time and then sleeps for a

long time. The shorter the active part is the better. This might also mean that the beacon transmits less per unit of time, making it less likely to be seen.

- Energy can be harvested from the surroundings in order to power the beacon or to prolong its battery life.

Energy consumption is also an important aspect in smartphones. Users want to be able to use the phone as long as possible between two recharges of the accumulators. Since this is an important selling argument, manufacturers have tried to reduce (or at least limit) the impact of scanning activity on battery life. The reason is that scanning for Bluetooth Smart devices can be an energy intensive activity. The phone goes in reception mode and regularly changes channels in order to cover the ADV frequencies. Many smartphones offer limited options to modify scanning duty cycles.

There is therefore a conflict between conserving energy on the beacon side and conserving energy on the smartphone side. To see as many beacons as possible, the smartphone should often scan (stay in reception mode), which costs more energy. One tendency is to shift the problem on beacons and have them increase their advertisement frequency. This leads of course to a more frequent replacement of beacon's batteries.

Another problem resulting from high advertisement rate is that of collisions. The collision rate increases with the rate of advertisement frames and with the number of beacons present in a given volume. If there is a high concentration of beacons in a place, this might result in a slow discovery time. In the case of applications that required the connected mode, this also means more energy consumed by the beacons, since they will advertise even longer before they can be seen and can go into connected mode [3,4].

There are consequences linked to this situation, for users, manufacturers and developers:

- For users. There can be a clear difference in performance, depending on the type of smartphone or on the scanning settings. This means bad user experience and frustration. In the worst case, it will erode the confidence of users in a product.
- For the developers of apps. This could mean difficult and time intensive debugging activities and loss of development resources. Developers are also confronted with systems or solutions that do not react in the same way for all smartphones (reliability issues).
- For developers of beacons. It is important to give enough flexibility to the beacon. In this way, service providers can adapt their beacon to the variety of smartphones that are used.
- For manufacturers of smartphones. As beacon-enabled applications grow, the way smartphones interact with them becomes important. A smartphone that does not scan "properly" might receive a "bad press".

Having faced such issues several times with our customers, we decided to build a test method that allows us to determine the performance of smartphones when they scan for beacons. To the best of our knowledge, this is the first time such a systematic analysis has been done.

II. TESTING REQUIREMENTS

In order to determine the requirements for testing scanners, it is important to understand how thes works. Fig. 4 shows the advertising and scanning activities of both an advertiser and a scanner. For a more detailed understanding, the user is encouraged to consult Bluetooth specification documents [5].

A beacon transmits data on 1, 2 or 3 ADV channels. This is an advertising event. The time between 2 advertising events is the advertising interval.

A scan activity normally consists of two parts:

- The part where the receiver of the smartphone is ON (this is the scan window). It can receive ADV frames, if both beacon and smartphone are advertising/scanning on the same channel, are within RF range of each other and if there are no perturbations leading to a destructive collision.
- The part where the receiver is OFF. The smartphone receiver does not consume energy here (for receiving frames). The longer that part is, the more energy is saved. However, the smartphone is "deaf" in this time.

The sum of ON and OFF durations gives the scan interval. Scan window and scan interval depend on the smartphone manufacturer. The number of consecutive scan intervals where the device scans the same ADV channel also depends on the manufacturer. This information is important in order to estimate how well a smartphone will successfully scan.

There are also other parameters such as receiver sensitivity, quality of the antenna, etc. that also affect the reception of frames. We were concerned with scanning activity in this work. The focus was on determining the scan interval and window interval of different phones

Activities needed to test the scanning behaviour of smartphones are summarised in the table below.

Activity	**What is needed**
Generation of ADV patterns to test the smartphone.	Appropriate HW/FW that can generate the needed pattern. Advertise fast enough to allow proper time resolution on the smartphone. Flexibility for frame size, contents, channels.
Capture of the pattern by the smartphone under test.	Appropriate app, working in controlled conditions. Captured data should be transferred to the analysis station.
Capture of the pattern by a reference device.	Appropriate scanner that serves as reference, in order to make sure that the pattern generated can be seen.
Comparison of the results.	Appropriate tools to capture, analyse and extract results.

To implement those activities, appropriate HW/SW elements and apps were designed or assembled (Fig.5, Fig.6).

The ADV pattern is generated by a Nordic nRF52 kit device. Firmware was written to enable fast generation of ADV. This allows the simulation of frames coming from different beacons and that are very close in time. We can generate events with interval of about 1ms.

A dongle kit from Cypress is used as reference sniffer. The sniffer is attached to a PC. Its parameters can be modified.

Matlab scripts were written to allow the analysis of the collected data.

An app was written (for iOS and Android) that allows the smartphone to collect data, log the information, compute some statistics.

III. TESTS SET UP

The following settings were used for the tests:

- Advertising interval = 12ms (this was found to be a good compromise between data size and measurement time resolution. For some phones, a 1.3 ms interval was also used). The low interval helps approach the behaviour of asynchronously operating beacons (emulation of beacons).
- 2000 advertising events in total were sent to the smartphone under test. This is equivalent to 6000 packets in total and a test duration of ca. 25s (3 ADV channels).
- Tests are conducted in an office environment and the distance between beacon and smartphone is less than 1m.
- In order to help in the result evaluation, frames contain the advertising channel number and the advertising event number

On the app side, the following was done:

App for android:

- The frame has 15 bytes of payload. The app filters and processes the packets with the advertising address decided by us.
- The frames are sorted according to the channel on which they were received.
- Calculation of the percentage of correctly received packets and received channels.
- Also calculates if they were received on more than 1 channel (one ADV event on multiple channels)

App for iOS (same as app for Android with following variations):

- Does not allow filtering for the advertising address
- Whole frame is analysed

The following Android and iOS devices were tested:

Samsung Galaxy J3 (Android 5.1.1), Motorola G (Android 4.4.2), Google Nexus 5X (Android 7.1.1), Samsung Galaxy S5 (CyanogenMod), Google Nexus 5 (Android 6.0.1)

iPhone 5C (iOS 10.3.1), iPad 3rd Generation (iOS 9.3.5)

IV. RESULTS

The test results are shown on Fig. 7 and Fig. 8 (the reader is encouraged to look at those figures for more information).

It was possible to determine the scan parameters of most of the smartphones. This information is normally not given by the manufacturer. This was not possible in the case of the Motorola G. because of the instability of the results.

It was also possible to determine the percentage of frames received by a smartphone. This number normally correlates well with the scan interval and window interval parameters.

It can be seen that some smartphones are poor at scanning. This has been conformed with real life trials that we made using our beacons. Devices that scan often tend to see more beacons or to see then faster.

V. CONCLUSION

In this work, we have designed and implemented a platform that allows us to investigate the behaviour of a smartphone when it scans for beacons. This information can be used to test how appropriate a given smartphone is in certain applications. It can also be used by developers to determine the possible reasons behind inconsistencies in an application. It can be used to advise users on which smartphone to use in order to get a better experience when dealing with beacon-based applications.

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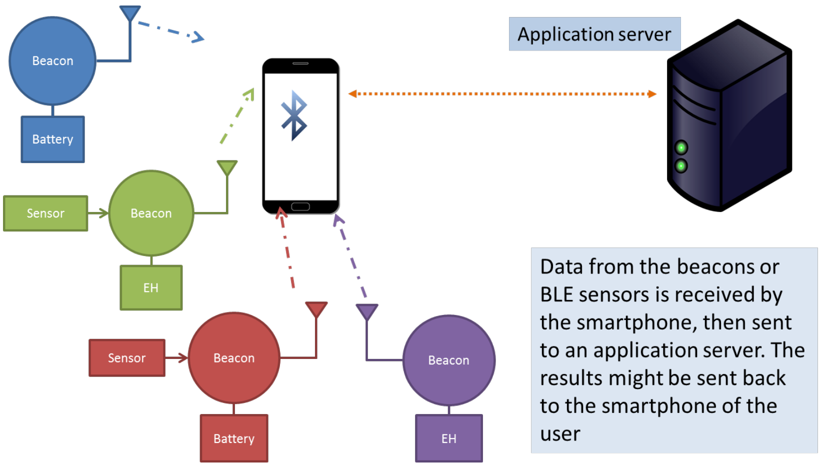


Fig.1 Basic system. The smartphone scans for presence of beacons that are in its vicinity.

Fig.2 Sensor powered using energy harvesting

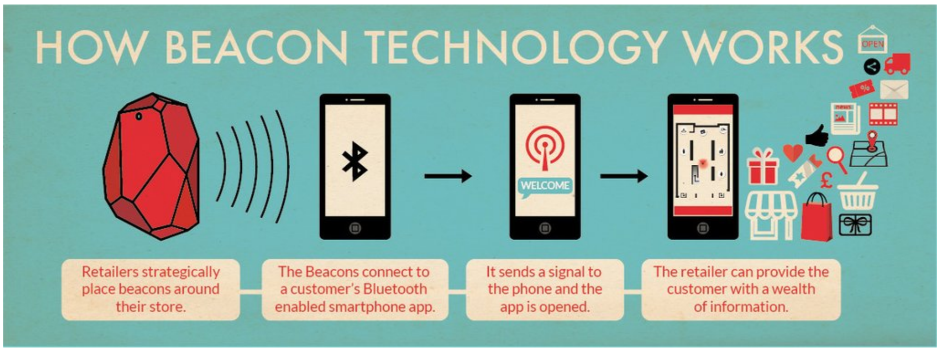


Fig.3 use of beacon technology (source Business Insider) [in ref 1]

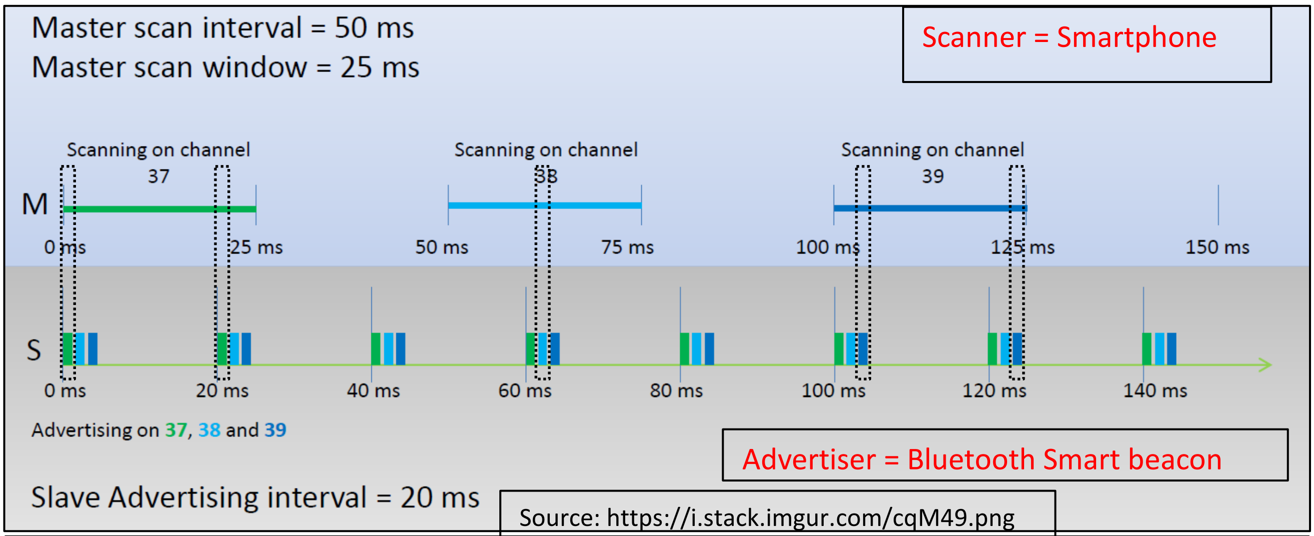


Fig.4 Advertising and scanning operations

- Advertising event: One advertising packet is sent on all three advertising channels
- Advertising interval: time between two advertising events
- Scan interval: time between two consecutive scans (channel switches)
- Scan window: time in which the Smartphone scans inside a scan interval

These parameters are different for every smartphone!

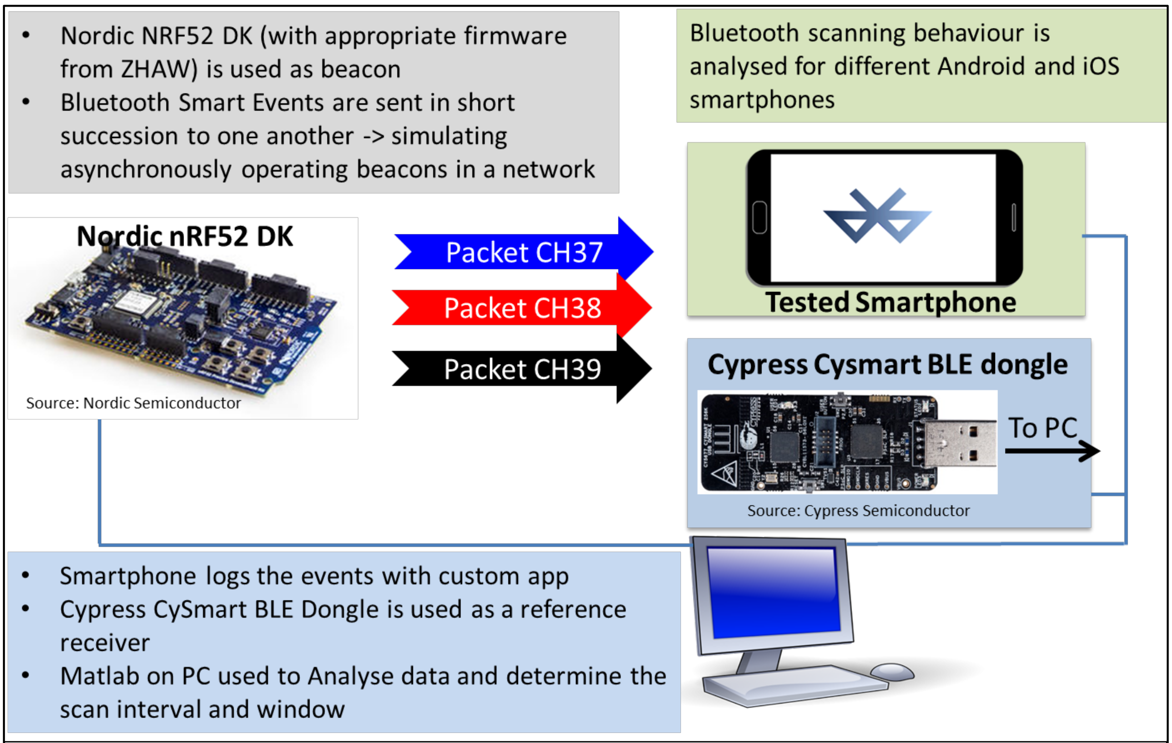


Fig.5 Elements used for the tests
The nRF52 kit generate the test patterns that are captured by the smartphone under test and the reference sniffer. The results are analysed on a PC using a Matlab software. Appropriate firmware and apps are needed.

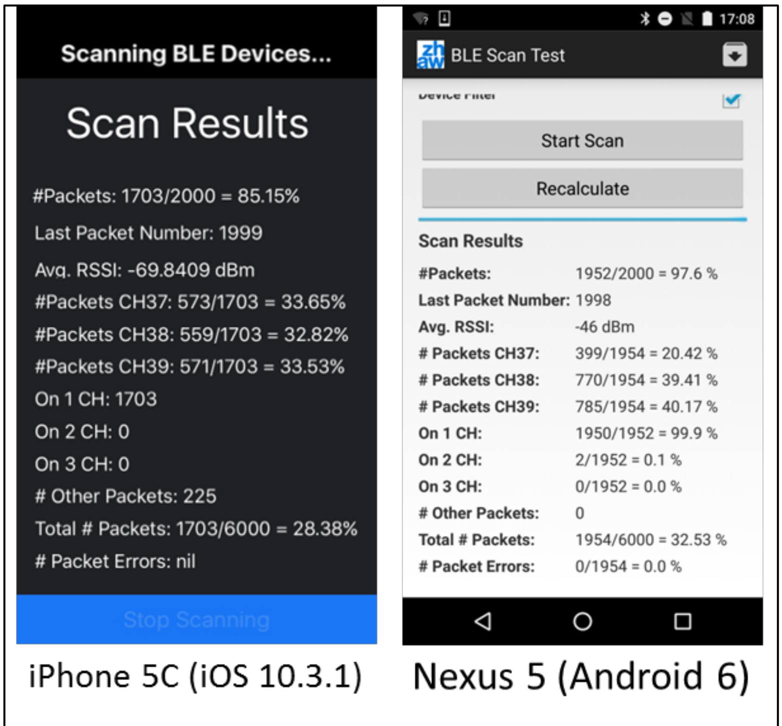


Fig.6 A view of the scan results displayed on the smartphones

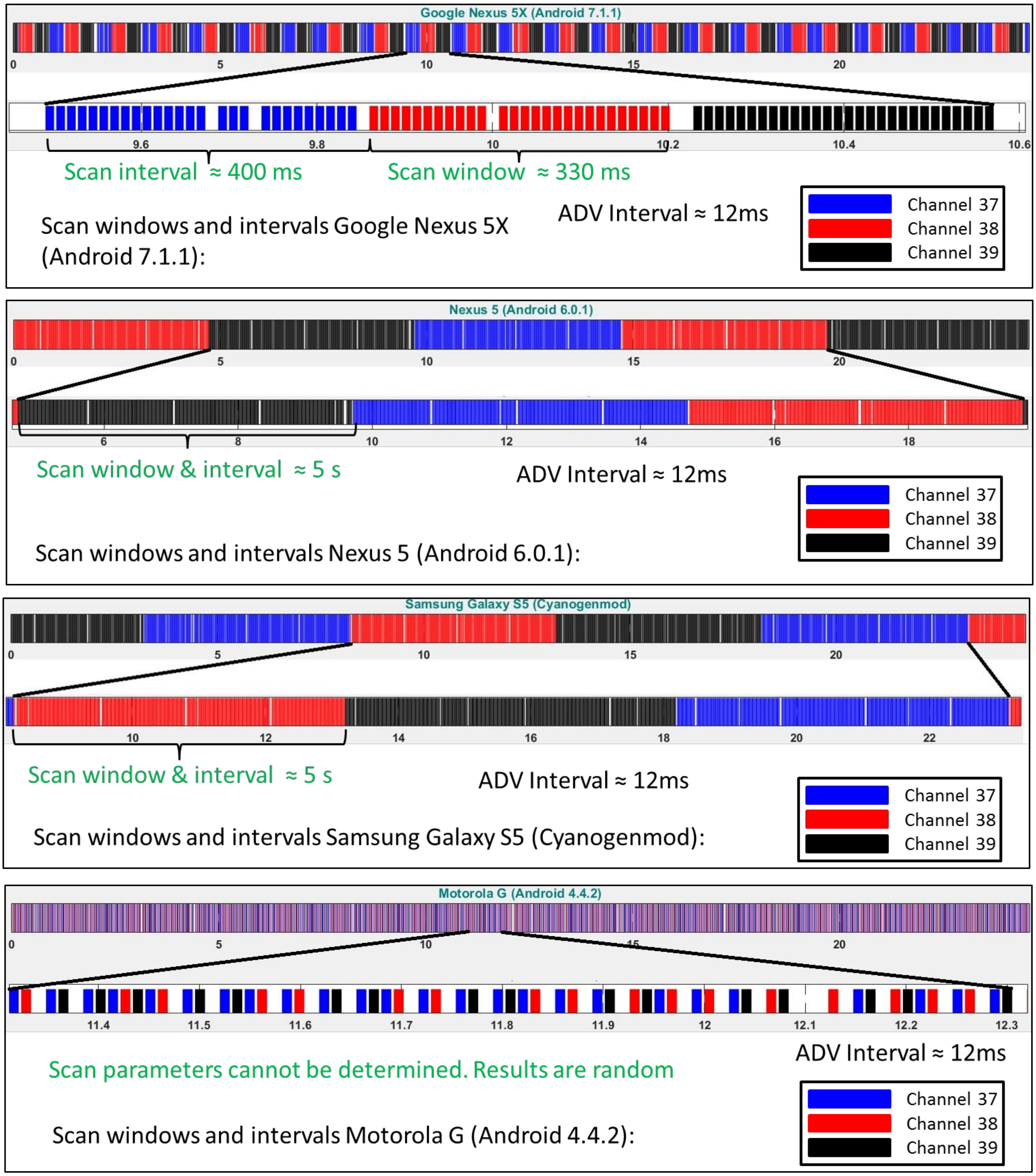
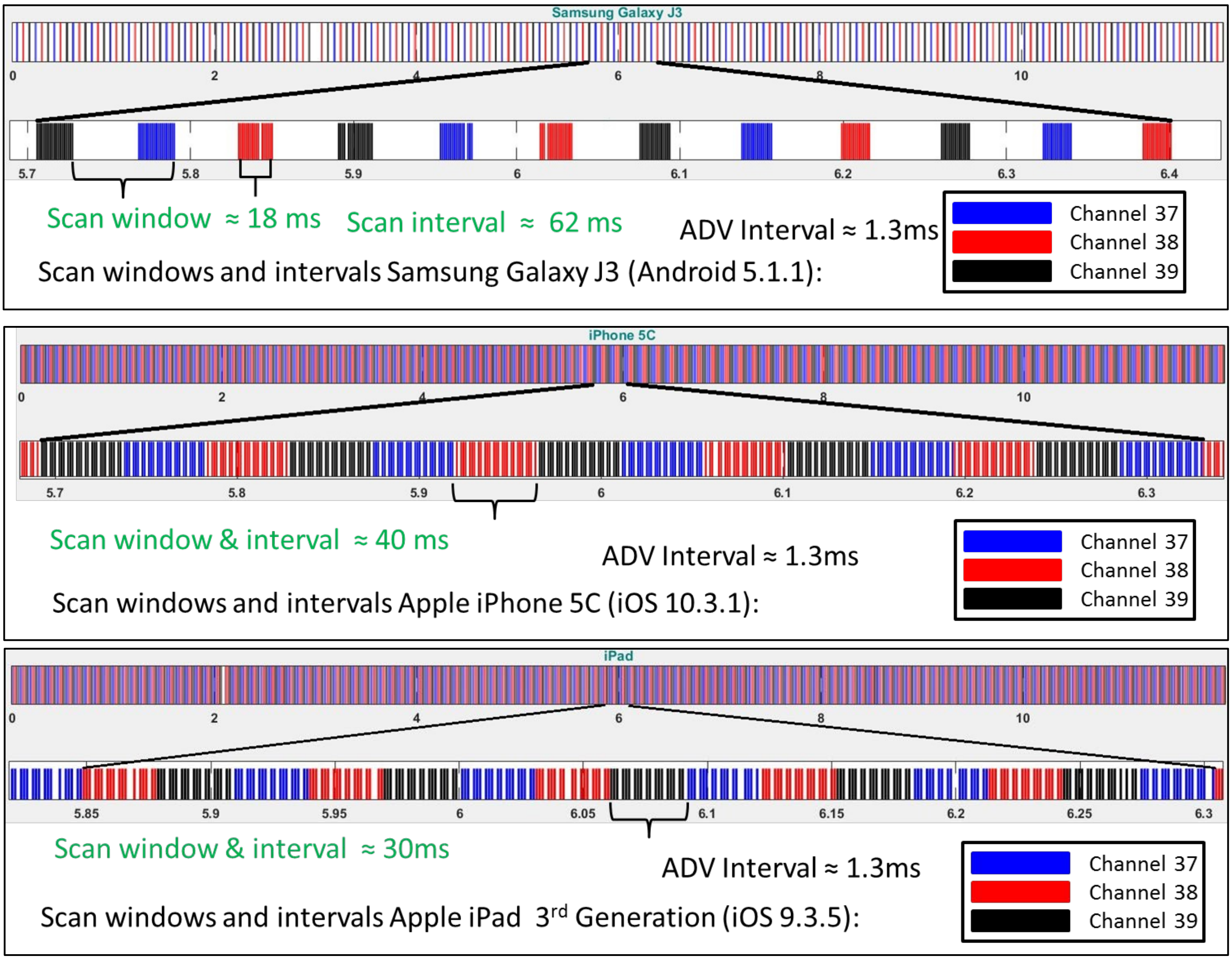


Fig.7 Results showing the scanning pattern of the different smartphones. Received frames are shown in a colour representing the channel. A long absence of colour indicates that the phone is not scanning. The scan window and scan interval can be calculated. In the cases above, an advertising interval of 12 ms was used.



	Samsung J3		Motorola G		Nexus 5X		Samsung S5		Nexus 5	
Scan Duty Cycle	29 %		-		83%		100%		100%	
Event Count	533	26.65%	1456	72.80%	1801	90.05%	1952	97.6%	1952	97.6%

	iPhone 5C		iPad	
Scan Duty Cycle	100%		100%	
Event Count	1703	85.15%	1580	79.00%

	Cypress Sniffer	
Scan Duty Cycle	100%	
Event Count	2000	100.00%

Overall Reception

- The J3 has by far the worst scanning of all phones, it only receives about 25% of the total of sent events. This can be explained by the low scan duty cycle.
- Unfortunately the duty cycle for the Motorola G can't be determined. It receives about 70% of the sent events.

Fig.8 Results showing the scanning pattern of the different smartphones. In the cases above, an advertising interval of 1.3 ms was used. The final table also shows the percentage of events that were received.