Scan-Or-Not-To-Scan – Balancing Network Selection Accuracy and Energy Consumption

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Abstract— **One of the factors influencing the quality of a mobile user's multimedia experience is the rate at which they can receive data. To connect to the wireless network that best meets their needs a user must first detect available networks and then select the most suitable network. However, it may not always be in the best interest of the user to actually invoke a network detection and selection strategy. Simulation results show that in certain conditions it is detrimental to the end user to switch networks, even when an apparently 'better' network is detected.**

In order to help decide when it is appropriate to invoke network detection and selection algorithms, this paper introduces the Scan-Or-Not-to-Scan (SONS) framework. SONS decides based on environmental inputs, when to invoke or not a network detection and selection algorithm. The use of the SONS framework enables the user to conserve energy by shutting down unused interfaces and maximise data throughput. Reducing the number of unnecessary handovers helps maintain the mobile user multimedia quality of experience.

Keywords-wireless communications, advisory system, network selection

I. Introduction

Widely available wireless access networks and powerful, multi-homed mobile devices make it possible for a mobile user to be always "best connected" and has led to an increased demand for multi-media content. For instance Cisco estimates that 69% of all web traffic will be video by 2017 [1].

Being best connected requires the user device to check for the presence of available networks with more suitable characteristics than the one to which it is currently attached. The device might also seek to compensate for any loss of connectivity to one network by connecting to another available network. These activities imply the need for some type of network detection and selection strategy.

Although multiple wireless networks might be available to a mobile user it is not always beneficial to continuously scan for "better" networks to connect to. In fact, under certain circumstances it may actually be detrimental to a user's overall data transfer rate and the battery life of the device to run network detection and selection algorithms.

A great deal of research has been conducted in the area of network selection [2, 3, 4], the focus of which has been on the detection and then selection of the next wireless network to connect to. The assumption always seems to be that if a network capable of delivering greater throughput is detected then a user should connect to it with no consideration as to the possible duration of the new connection.

In urban environments wireless coverage areas (other than those of mobile phone networks) can be of very limited size and the rate at which a mobile user is travelling determines how long they will remain within the coverage area. The higher the mobile user speed is, the less time they spend in the coverage area. Establishing a connection to a wireless network always takes some period of time which reduces further the amount of time available to a mobile user to establish a useful connection.

In circumstances in which a useful network connection cannot be established, it is clearly in the interest of the mobile user not to attempt to detect and connect to wireless technologies that have very limited range. To the best of our knowledge, the problem of when it might not be appropriate to conduct network detection and selection operations has not been addressed.

In this context, this paper proposes **Scan Or Not To Scan (SONS)**, a novel framework that helps decide whether or not it makes sense to run a particular network selection algorithm, including in the presence of multiple, apparently 'better' wireless networks. By deciding to run or not run a network selection algorithm there is potential for energy saving by activating wireless interfaces only when necessary, reducing the number of unnecessary scans, increasing the total amount of data downloaded by not interrupting established connections unnecessarily and improving QoS for streamed content by reducing the number of handovers.

The remainder of this paper is organised as follows, Section II examines related work, Section III presents the results of our real world survey and our simulations and Section IV simulation results and analysis. Section V discusses the SONS framework and Section VI draws conclusions.

II. Related Work

Many popular smart phones require daily recharging [5], mostly due to the number and complexity of the services users access during the day. In order to get the most from their devices users need to conserve energy by ensuring that unnecessary operations are not being carried out and that unused components consume as little power as possible.

Over the recent years the number of wireless networks and technologies deployed has increased and so has the sophistication of the network detection and selection algorithms. Increasingly, decision making techniques such as Fuzzy Logic [6] have been employed to deal with the increased number of available networks and the parameters used as decision making metrics [7].

A direct consequence of using ever more sophisticated selection algorithms is that they may take longer to reach a decision on which wireless network to connect to. This is a serious issue for mobile users, who, depending on the speed at which they are travelling may have a severely limited amount of time in which to detect and select a wireless network before they pass out of range. Research [8] has clearly demonstrated that a mobile user might only be in range of a wireless AP for a matter of seconds.

Network selection algorithms are concerned with selecting the most appropriate network to connect to in the prevailing circumstances. However, the amount of time required to scan all available wireless networks has been identified as a major delay factor in wireless operations [9]. Various strategies to reduce the scanning delay have been proposed in [10].

Due to the constraint placed on mobile devices by battery capacity, careful consideration should be given as to how energy is consumed by a device. Wireless adapters consume energy during operation [9, 11] and continue to do so even while in standby mode; the amount of energy consumed obviously rises with the number of active wireless interfaces. It has also been demonstrated that transferring data over a mobile phone network consumes more energy than transferring the same amount of data over WiFi [12].

All wireless networking operations consume energy and network detection and selection algorithms should only be run when there is a realistic prospect of a useful connection being established. Additionally once the radio hardware has been activated, the actual amount of data transferred has little further impact on energy consumption. Therefore to make the best possible use of a wireless link it is important to send as much data as possible over the link since the energy cost associated with that network operation has already been incurred. For energy conservation, it is better to transmit data in large bursts and then not transmit anything allowing the interface to sleep, than transmitting little over longer periods of time and reducing the sleep periods.

III. The SONS Framework

The proposed **Scan Or Not to Scan (SONS)** framework abstracts from the user the problem of having to decide when it makes sense to invoke a network detection and selection algorithm. The **SONS** framework is designed to be generic and to work with any network detection and selection algorithm specified by the user.

The proposed SONS framework takes into consideration the fact that the speed at which a mobile node is travelling has a significant impact on whether or not a useful connection can be established to a wireless network and uses the average speed at which the mobile node is travelling as an input to the decision making process. It is important to keep in mind that SONS is not a network selection process, but rather a mechanism by which a decision can be made as to whether or not to execute the associated network selection strategy.

Threshold Speed

In order for a network connection to be of any benefit to an end user, it must persist for some period of time that enables the user to do something useful. The amount of time a mobile user remains in range of an AP depends on the coverage area of the AP and the speed at which the mobile user is travelling. The period of time required to carry-out useful tasks should be greater than:

$$CA/US - (sd + nad + cd)$$

where CA is the AP coverage area in metres, US is user speed in metres per second, sd is the scanning delay, nad is the time taken to establish a connection to an AP and cd is the amount of time required to open a web page in a browser.

The largest AP coverage area observed during our survey (Section IV for details) was 80m and the smallest was approximately 13m with many clustered around 35 – 40 metres. For the purpose of calculating a threshold speed we assume an average AP coverage area of 40 meters. The duration of wireless scans carried out was on average 3.6 seconds, similar to scan delays in [9], and an average connection delay of 4.6 seconds was experienced. The time taken to load a web page in a browser obviously depends on the content of the web page itself. In tests the Google search page loaded in 2.5 seconds and Gmail's login page loaded in 3.3 seconds, based on these values we consider the shorter load time of 2.5 seconds.

Average combined delay = 10.7seconds (3.6s + 4.6s + 2.5s)

Therefore, a mobile node traversing an AP coverage area of 40m would need to be moving at a speed of approximately 40/10.7=3.7m/s in order to make a useful connection, value which is the threshold speed in the SONS framework.

Bus-Train Mode

In certain circumstances it is possible that a mobile user could travel at a relatively high speed and still be in a position to engage in network selection. For example, many public transport systems provide free on-board WiFi for passengers. In this case the mobile user is potentially travelling at a high speed yet remains within the coverage area of the on-board wireless AP and therefore network selection should be enabled. Based on the authors' experience with the free on-board WiFi service provided by both private and public transport companies, a user is required to accept terms and conditions at the start of each session and to click on a "Connect" button. This makes automated connection to these services difficult. It is envisaged that a user of SONS, the proposed framework would have to manually select a "Bus-Train Mode" option, which would enable network detection and selection mechanisms to operate anytime.

For mobile users time is of the essence since the window of opportunity for making decisions may be very short. Complex algorithms require more time to execute than do simple algorithms. Consequently a very simple decision making process is considered in which there are two inputs only, enabling decisions to be made quickly.

The SONS framework has two components, a *Movement Analysis Unit (MAU)* that takes input from the mobile devices on-board GPS and accelerometers and compares the current speed with previously recorded speed to determine if the mobile user's speed is constant, increasing or decreasing based on the average speed calculated during the previous t=10 seconds.

Output from the MAU is fed into the *Decision Making Unit (DMU)* in addition to information on the mode of transport, if any, being used. The block diagram presented in Figure 1 shows the relationship between the GPS/accelerometer inputs, MAU, DMU and the user defined network selection algorithm.

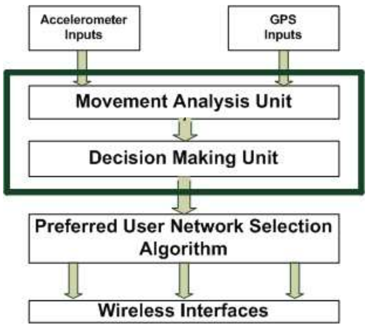

Figure 1 SONS System Block Diagram

The decision making process (outlined with dashed line in Figure 2) takes place within the DMU, illustrated in the block diagram included in Figure 1. The pseudo code for the decision making process is presented in Algorithm 1.

Figure 3 Wireless Environment Survey performed in Dublin, the direction of Mobile Node (MN) travel is shown by arrow

Algorithm 1:

```
Set system to ON
While system ON
If Bus/Train mode on
  Activate appropriate interface
        If netwk available
          Start netwk selection process
        End if
      End if
    Else
     Get MAU input
       If speed = 0 or speed < threshold
         Activate appropriate interface
        Start network selection process
      End if
    End else
```

Algorithm 1 Decision Making Process

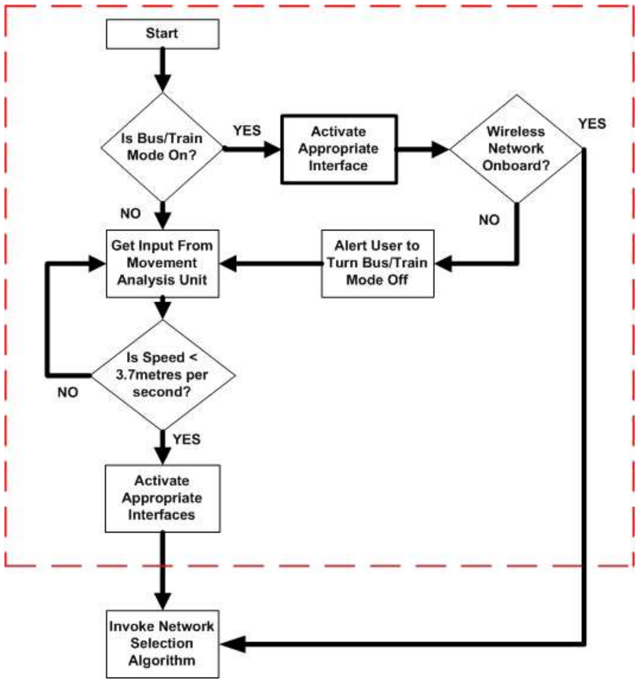

Figure 2 The SONS Decision Making Process

IV. Real World Survey, Modeling and Simulations

In this research, a two phase approach was taken as follows: Phase I was concerned with conducting a survey in an urban environment to examine wireless conditions. Phase II was concerned with constructing a realist model based on our survey results.

Phase I AP Survey

A survey of WiFi APs was conducted in an area of Dublin City centre, illustrated in Figure 3, using a Nexus 7 tablet and the Wigle [13] wardriving application. The wardriving application used the device's on-board GPS unit to map the locations of detected WiFi APs. The buildings in the survey area are old, solidly constructed with brick and stone structures; the nature of their construction means that the walls very effectively block radio signals, with a limiting effect on the coverage area of the WiFi APs.

Connection Delay

It was also examined how much time was required to establish a connection to a WiFi AP and a data connection to a 3G mobile phone network, respectively. The amount of time required to establish a connection to an AP was on average 4.5 seconds. A data connection was established to the network of a 3G mobile phone provider and the observed amount of time required to establish a connection was in excess of 7 seconds. Connections were established to several WiFi networks and the download speeds were measured using a connection speed measurement tool [14], the results are presented in Table 2.

Meteor 3G Network Performance					
Ping	Avg. Download	Avg. Upload	Reliab.		
611 ms	2 Mbps	0.5 Mbps	82%		
Connection Delays to 3G Network [in seconds]					
Inside	7.69	7.28	7.13	6.91	7.11
Outside	7.48	7.28	10.6	7.17	7.35

Table 1 Device: HTC Desire 380, 3G network [17], user stationary, connection time in seconds

WiFi Connection Test Times (Seconds)					
Location	Distance from AP	Test 1	Test 2	Test 3	Test 4
Home Network	17 m	5.0	4.7	4.25	5.03
Home Network	2 m	5.33	4.7	3.39	5.06
Bus On-board AP	unknown	3.57	3.72	3.49	3.85

Table 2 WiFi Connection test times

Phase II. Modelling and Simulation

The results presented in this paper were generated by a series of NS-3 [15] simulations modelled on the survey results from Phase I. The simulations performed were concerned with models of two wireless technologies: WiFi and 3G. In the simulations the average observed WiFi AP coverage area and the estimated distance between APs to create the node layout for our NS-3 simulations was considered. The observed download speeds [Table 3], connection establishment delays [Table 2] and total connection times were used to determine the number of data packets received from each network AP at the mobile node.

The simulation environment consisted of three nodes representing WiFi APs and a single node that represented the 3G network. The mobile node travelled in a straight line between the 3 WiFi APs and the 3G node to the edge of the simulation area. The diameters of the APs coverage areas were 20, 40 and 50 metres, respectively and the coverage pattern of the 3G network was replicated by permitting omni-directional connectivity to the node representing the 3G network.

Observed Download/Upload Rates at Public WiFi APs		
Ping Times	Download	Upload
104ms	2.47 Mbps	0.9 Mbps
630ms	6.0 Mbps	1.6 Mbps
721ms	4.93Mbps	1.4 Mbps

Table 3 Sample Observed Download/Upload Rates and Ping Response Times

Assumptions

For the purposes of the NS-3 simulations the following assumptions were made:

- The mobile node can connect to any detected WiFi AP
- Connections to either the WiFi APs or the 3G network were never refused
- Once a connection was established the data transfer rate for that connection remained constant
- When not in use a wireless interface is shut down
- When an interface is brought back up there is no delay in beginning operations apart from an appropriate connection delay (including scanning delay)
- If the mobile node was not connected to an AP a scan was carried out every 5 seconds, longer scan intervals could result in an AP being missed

Simulation Scenario 1

A mobile node moves along a straight line route pausing by two locations for a period of 90 seconds each time, these pauses imitate the movement pattern caused by traffic lights and pedestrian crossings. The mobile node traveled the route a total of nine times, each time at a different speed.

During the first set of simulations the mobile node scans for WiFi APs whenever it is not connected to one, the scan interval is 5 seconds.

Simulation Scenario 2

A mobile node moves along a straight line route pausing at two locations for a period of 90 seconds at each location, these pauses imitate the movement pattern caused by traffic lights and pedestrian crossings. The mobile node travels the route a total of nine times, each time at a different speed.

During the second set of simulations the mobile node only scans for WiFi APs when it is stopped and not connected to an AP, simulating the functionality provided by the SONS framework.

Total Amount of Data Received at Mobile Node in MB			
Node Speed	Data RX No-SONS	Data RX SONS	SONS % Difference
1.4mps	108.51	108.51	0
2mps	99.99	99.99	0
3mps	122.05	122.05	0
3.7mps	122.54	122.54	0
4mps	99.65	99.65	0
5mps	100.31	105.87	5.5% increase
6mps	104.39	105.31	0.88% increase
7mps	99.29	105.44	5.83% increase
8mps	99.59	105.47	5.58% increase
9mps	62.36	105.47	40.87% increase

Table 4 Total amount of data in megabytes received at the mobile node

In each of the simulations when the edge of a WiFi AP's coverage area was detected a delay of 8 seconds, the average period of time equal to the connection delay plus the scanning delay observed during the survey, was implemented before data was received at the mobile node. During the delay period the connection to the 3G network, if one existed, was maintained. Once a connection to the AP was established the 3G interface was shut down to conserve energy. When the limit of the AP's coverage was reached the transfer of data between the AP and the mobile node was halted immediately.

Following loss of connectivity to a WiFi AP a 7 second delay in establishing a connection to the 3G network was introduced. This delay was introduced to replicate the real-world delay observed during the establishment of a connection to a 3G data network. In the event that another WiFi AP was detected and could be connected to before the 3G link was established the new WiFi link was established and the 3G connection attempt aborted.

The various node speeds employed during the simulations were 1.4 metres/per/second (mps), 2mps, 3mps, 3.7mps (threshold speed), 4mps, 5mps, 6mps, 7mps, 8mps, and 9mps.

V. RESULTS & ANALYSIS

Table 4 presents the amount of data received by the mobile node for each simulation, at each of the nine speed values used. There is no variation between the amounts of data received at the lower speeds since a mobile node will scan for available WiFi networks when not connected to one as long as its rate of travel is below the threshold value of 3.7mps even when SONS is implemented.

At higher speeds, the use of the SONS framework presents the user with an increased data transfer rate. This is due to the reduction in handoffs between networks.

Energy Consumption per WiFi Scan (mWatts)					
Node Speed	No. Scans No-SONS	Scan Energy 150mW per scan	No. Scans SONS	Scan Energy 150mW per scan	Energy Saving (mW)
1.4mps	7	1050	7	1050	0
2mps	12	1800	12	1800	0
3mps	16	2400	16	2400	0
3.7mps	18	2700	18	2700	0
4mps	18	2700	18	2700	0
5mps	20	3000	2	300	2700
6mps	20	3000	2	300	2700
7mps	21	3150	2	300	2850
8mps	21	3150	2	300	2850
9mps	24	3600	2	300	3300

Table 5 Estimated energy consumption due to WiFi scanning operations

All networking operations consume some amount of energy. Table 5 presents the estimated energy consumption for scanning operations during each simulation. These results complement the extensive tests that demonstrated that network scans conducted by Android devices consume approximately 150mW of energy per scan.

In the first set of simulations the mobile node scanned for WiFi networks whenever it was not connected to a network. The scan interval was set to 5 seconds in order to avoid missing any AP along the line of travel. It is possible to configure the device to use an increased scan interval, but at higher rates of speed AP might pass out of range before detection.

When the SONS framework is deployed, there is a dramatic reduction in scanning activity at rates of travel over the threshold value since the node will only scan for networks when stopped or travelling at low speeds. This leads to a reduction in energy consumption.

The strategy adopted in Simulation Scenario 2, the SONS framework, benefits the end-user in 3 ways:

- The rate at which data is received is stabilized at higher speeds instead of decreasing
- If a mobile node is travelling at a speed greater than the threshold speed no attempt is made to connect to a detected WiFi AP thereby reducing the number of disruptions to data transfer operations due to handoffs and also reducing the amount of time lost to connection delays
- The reduction in scanning activities reduces the amount of energy consumed, not activating WiFi interfaces unless there is a reasonable chance of establishing a useful connection also helps conserve energy

VI. Conclusions

Ubiquitous wireless networks and multi-homed mobile devices make possible for a mobile user to be always "best connected" and to consume multimedia content on-the-go. Opportunities may exist to seek out and connect to a 'better' network than the current connection but this consumes energy and mobile users constrained by dependence on a battery must protect their resources where possible.

It was shown that it is not always appropriate to engage in network detection and selection since, under certain circumstances, this can reduce the total amount of data transferred. Additionally, initiating wireless operations when they are of no benefit, results in the unnecessary consumption of energy. This paper presents the SONS framework which abstracts from the user the decision of whether or not to carryout network detection and selection operations. Careful management of network discovery operations can help maximise data transfers, reduce energy consumption and protect the user experience by reducing the number of unnecessary handovers.

The task of developing software to implement the decision making process described in this paper and testing it under real word conditions remains to be completed.

References

[1] Cisco Systems Inc, "Cisco Visual Networking Index: Forecast and Methodology, 2013- 2018", 2014, Whitepaper, Available:http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.pdf [12 September 2014]

[2] Mohamed, L.; Leghris, C.; Abdellah, A., "A survey and comparison study on weighting algorithms for access network selection ", 9th Annual Conference on Wireless On-demand Network Systems and Services (WONS), 2012 , pp. 35 - 38

[3] Han P., Tian H., Xie W.; Zhong W., Li N., "Network selection in heterogeneous wireless networks using learning automata", International Conference on Wireless Communications & Signal Processing (WCSP), 2012, pp. 1–6

[4] Wang, H., Laurenson, D. I., Hillston, J., "A General Performance Evaluation Framework for Network Selection Strategies in 3G-WLAN Interworking Networks", IEEE Transactions on Mobile Computing, Vol. 12 , Issue 5, 2013, pp. 868 – 884

[5] Byrne, K., "Best battery life 2014 - 60 smartphones tested", article, available at: http://www.expertreviews.co.uk/mobile-phones/1402071/best-battery-life-2014-60-smartphones-tested [22 November 2014]

[6] Lotfi A. Z, "Fuzzy Logic = Computing with Words ", IEEE Trans. On Fuzzy Systems, vol. 4, no. 2, May 1996

[7] de Miranda Rios, V. ; de Lira Gondim, P.R. ; de Castro Monteiro, C., "Use of fuzzy logic for networks selection in heterogeneous wireless environment", 14th International Conference on Advanced Communication Technology (ICACT), 2012, pp. 798 - 803

[8] Frangiadakis, N., Kuklov, D., Roussopoulos, N., "PEGASUS: 802.11 connectivity at high speed ", Globecom Workshops, 2007 IEEE, 2007 , pp. 1 – 8

[9] Trestian, R., Moldovan, A., Muntean, C. H., Ormond, O. and Muntean, G.-M., "Quality Utility modelling for multimedia applications for Android Mobile devices," IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), 2012, pp. 1–6.

[10] S. Park, J. Choi, T. Kwon and Y. Choi, "Fast Handoff Support in IEEE 802.11 Wireless Networks", IEEE Communications Surveys & Tutorials, Vol. 9, pp. 2-12, May. 2007.

[11] Kalic, G. ; Bojic, I. ; Kusek, M., "Energy consumption in android phones when using wireless communication technologies", Proceedings of the 35th International Convention MIPRO, 2012 , pp. 754 – 759

[12] Trestian, R., Ormond, O., Muntean, G.-M., "On the impact of wireless network traffic location and access technology on mobile device energy consumption", Local Computer Networks (LCN), 2012 IEEE 37th Conference on , 2012 , pp. 200–203

[13] WiGLE Wardriving application, available at: https://wigle.net/, [30 June 2014]

[14] OOKLA Speedtest for Android, available at: http://www.speedtest.net/mobile/android/, [30 June 2014]

[15] NS-3 Network Simulator, available at: http://www.nsnam.org/, [10 May 2014]

[16] Dublin City Centre Speed Limits, http://www.dublincity.ie/sites/default/files/content//RoadsandTraffic/generaltrafficmeasures/Documents/TD%203369_06%2030%20km%20hr%20City%20Centre%20approved%20%20Mar%202011%20.pdf, [10 April 2015]

[17] Irish Mobile Operator Performance Metrics, available at: http://opensignal.com/networks/ireland/meteor-coverage, [15 August 2014]