CoolSpots: Reducing the Power Consumption of Wireless Mobile Devices with Multiple Radio Interfaces Review

MobiSys is an ongoing annual international conference on mobile systems, applications, and services. At the time of this paper it was the fourth installment of the conference. While mobile phones have been around for a long time now, devices capable of running significantly powerful applications was relatively new, hence the young age of the conference.

The CoolSpots system enables wireless mobile devices to automatically switch between radio interfaces such as WiFi and Bluetooth, helping increase battery lifetime. The main goal of the paper is to explore the policies that enable a system to switch between these interfaces and provide quantitative measurements. The systems and policies will not require any changes to implement CoolSpots, and changes to existing infrastructure will be minimal. Results will be presented for commonly used applications like file transfers, web browsing, and streaming media. Experimental validation shows that the CoolSpot system can save more than 50% energy consumption of the wireless subsystem.

In advanced mobile devices like PDAs and smart-phones, the wireless communication subsystem is responsible for a significant portion of the total power consumption. These devices are increasingly being equipped with multiple radio interfaces to handle different connections--Bluetooth for personal-area, WiFi for local-area, and GPRS for wide-area. The idea of switching among radio interfaces to save power consumption has been researched before. By using the appropriate radio for the task at hand, overall battery life can be extended. For example applications with low network requirements can use the low-power/low-bandwidth interface and dynamically switch to the high-power/high-bandwidth interface if/when necessary. CoolSpots explores the policies required to enable switching between interfaces.

The contributions of this paper are the CoolSpots model which demonstrates the advantages of utilizing multiple radio interfaces while taking their different transmission ranges into account, and a suite of policies to guide the automatic switching based on a variety of metrics. The CoolSpots system does not require application modification, or much chance to infrastructure, making it a fairly easy system to deploy and integrate into existing systems.

Latency and bandwidth requirements vary significantly among various applications, i.e. frequent low-bandwidth control messages to high-bandwidth video streaming. There are currently two dominant short range wireless standards frequently incorporated in mobile devices—WiFi and Bluetooth. Wifi offers high-bandwidth local-area coverage up to 100 meters, while Bluetooth provides a low-power usage communication effective up to 10 meters. The CoolSpots project aims to use both radios to provide a single logical wireless channel improving power consumption.

While WiFi offers much higher bandwidth than Bluetooth—11 Mb/s for 802.11b Wifi, and 1Mb/s for Bluetooth, it consumes significantly more power—during active data transfer 890mW for Wifi, and 120mW for Bluetooth. This difference in power consumption is due to Bluetooth having a limited range, and simpler radio architecture. Even radios in an idle state consume a significant amount power. The typical use of mobile phones is that wireless devices are actually communicating for a small percent of the time the device is on. Bluetooth is optimized for this, and runs at a very low power state with only a 2% power duty-cycle and consuming only 1mW, while remaining discoverable and ready for connection setup. WiFi on the other hand, consumes around 250mW even with power saving mode (PSM) enabled.

Another difference between WiFi and Bluetooth is the communication ranges, and the required power consumption to support them. The distance between communicating endpoints has an affect on the radio's performance in terms of throughput and latency. The further the endpoints, the more channel noise, resulting in more retransmissions. These factors also contribute to the higher power consumption of WiFi over Bluetooth. CoolSpots takes bandwidth requirement, power, and distance into account in determining the optimal radio configuration. Also, to help save power the WiFi radio can be turned off when not being used.

CoolSpots is a combination of WiFi and Bluetooth to provide improved communication capabilities for mobile devices within a CoolSpot-enabled region. CoolSpots provides a concrete implementation of the generic concept of using multiple radio interfaces, and easily integrates with existing applications, systems, and devices. Based off of the idle power consumption of WiFi and Bluetooth radios, it has the potential to reduce power consumption ten fold for an idle system.

A CoolSpots enabled base station provides Bluetooth capability and can be simply added to an existing WiFi network, allowing mobile devices within reach to save power. By employing network routing changes, the base station can route traffic to mobile devices. The CoolSpot prototype co-locates the Bluetooth and WiFi radios in the same place, but this is not a requirement. The Bluetooth and WiFi radios could be in different physical locations, and if a mobile device is not close enough to a CoolSpot and wants to save power, it can fall back to WiFi using PSM mode.

The Bluetooth standard defines multiple power saving states, the most applicable being the sniff mode. This mode has a connected Bluetooth radio sleep for a specified cycle, and is automatically activated when there is any wireless data activity. With this mode it is possible to reduce the power consumption of Bluetooth considerably, while still being able to transition to an active communication. WiFi uses a similar method to save power (PSM), which has the radio cycle between sleep and active states. Interestingly, WiFi is more energy efficient than Bluetooth at an energy/bit standpoint.

The core of the CoolSpots model is the policies determining when to switch between radio interfaces. There are two key decisions—when to “switch-up” to WiFi and when to “switch-down” to Bluetooth.

The penalty for switching is the latency and energy overhead of de/activating the WiFi interface. The basic question is when is there not enough bandwidth available on the Bluetooth channel, and when is there too much unused bandwidth on the WiFi channel. This problem warrants a more complex answer than using static thresholds, due to the optimal bandwidth threshold changing as the distance between devices changes. Each policy has a set of corresponding modifiable parameters that change its sensitivity and responsiveness such as the sampling interval, switch threshold, etc. These parameters will cause the system to be more or less aggressive, and affect the energy consumption.

The bandwidth-x policies monitor bandwidth going across the active interface, and trigger a switch when it crosses above or below a specified threshold (X). The same threshold is used for both switch-up and switch-downs. To avoid spurious transitions, the bandwidth must exceed the threshold for a specified number of consecutive intervals in order to trigger the switch.

The cap-static-X policies use the measured channel capacity to switch up, and a static bandwidth threshold to switch down. A ping RTT is used to determine if the channel is saturated, as well as detect interference and obstacles.

The cap-dynamic policy uses the same switch up as cap-static, and a dynamically calculated threshold for the switch-down. It uses the measured bandwidth at the time of the switch-up as the threshold for switch-down.

A set of benchmarks provide the basis for evaluating the switching policies. There are two basic benchmarks, idle and transfer, which act as a baseline for evaluating the performance of the algorithms. However, these benchmarks are not descriptive of real-world systems. Streaming benchmarks are a set of the same MPEG-4 video streaming at various bit rates through the Real Time Streaming Protocol (RTSP). Two benchmarks represent standard web browsing traffic, and are derived from two different web sessions that have different traffic patterns.

The experimental setup is comprised of a Base Station (BS), Mobile Device (MD), Test Machine (TM), and Data Acquisition machine (DA), that work together to emulate a real life CoolSpot setup. The TM is given a list of benchmarks and a list of policy, which generates a series of results. All the relevant data is captured by the DA, and either graphically viewed or exported to a file. Network traffic from the TM to the MD is managed by the BS using ARP and modifications to its local routing table. A network address is assigned to the MD, and the packets are appropriately routed across either the WiFi or Bluetooth network. This way, for the MD to perform a switch it sends a “change route” message to the BS, and the BS modifies the local routing table. To account for location, the TM and BS are located on a moveable cart and manually positioned at different locations. This does not take into account movement while operating, however most people also don't compute much while moving.

The results show energy consumption can be reduced by as much as 75% without noticeably increasing the overall delay. Overall, the idle benchmark shows the necessity of incorporating a second radio channel in the system. An automatic switching policy will identify the idle state, and turn off the WiFi radio saving power.

Currently, CoolSpots only focuses on Bluetooth and WiFi, but the concept can be applied to other radio technologies such as GPRS or EDGE.

This paper was incredibly repetitive about even basic concepts and facts, especially in the first half. I lost count of the number of times they defined what CoolSpots does, and the benefit it has on power consumption. They even defined what the letters PSM stand for two separate times.

Overall it was written fairly well (excluding the excessive repetition), but one error is the line "...a technique similar to [6]." They used a reference without even eluding to what it might be, and in order to find out what the technique is similar to the reader must find the referenced paper and read its abstract. While this might not be an unintentional error, it was unpleasant from a readers point of view.

Some of the figures were poorly placed, for example figure one is at the top of the very first page and referenced for the first time on the second page. It is unpleasant for the reader to have to scroll or flip pages back and forth to interpret a figure.

Some of the graphs, while well done, were fairly complex to understand. Compared to the extremely basic level of understanding the written portion of the paper required, deciphering what the graphs represented took considerably more attention.

In the experimental setup, the mobile device and base station use the same hardware, and ran linux. In real life the base station is an access point, and the mobile device is just that—a phone, both running on very different hardware and neither run linux. Also for testing the effects of range, they moved the test machine and base station. In real life the base station doesn't move while powered on, and the mobile device moves quite frequently. In addition, they assured the reader that testing various fixed locations was okay because people rarely use their devices while moving. This is incredibly false, the purpose of mobile devices is in the name, mobility. I access the internet on my mobile device while moving on a daily basis, and this would have a significant affect on the switching policies and benchmarks.

The whole idea of CoolSpots is completely useless as in order to use this you must be within the range of both a WiFi and Bluetooth access points—both of which require power from a wall socket, so why not plug your mobile device into the wall and charge the battery while using it. Also all of their examples had home entertainment centers with access points, and most people who own cell phones also own a laptop and/or desktop computer at their home which is much more convenient to use for network activity. The only useful time for such an idea would be public places such as an airport, but again simply plugging the phone into a wall socket, or even via a usb charger to a laptop, completely defeats the purpose.

This paper was written in the pre-iPhone and Android days. The hardware of smart-phones has improved dramatically since, and can afford to run WiFi without a need for such a switching system. In addition, at least in the case of the iPhone the WiFi is turned off when in sleep mode, so there really is no WiFi idle time.

Overall this paper had little to no contribution, seeing as the idea of CoolSpots never caught on in the real world and they did not provide any other novel useful information. The whole paper seemed like a drawn out informercial advertising CoolSpots, with very little technical information except in the results.