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A Study on Energy Consumption of Different Wireless Devices

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Abstract:

This paper analyzes average energy consumption of Bluetooth, WiFi (802.11) and cellular networks for transmitting data produced at f bytes per second. It is assumed that a packet is created every t_{buf} seconds and sent to the respective module for transmission. Thus, data produced by an application in t_{buf} is given by $d = t_{buf} * f$ bytes, neglecting packet overhead. The experiments are carried out by taking some real wireless devices and energy consumptions are recorded with the standard watt-meter. After getting the actual scenario of energy consumption of wireless network we tried to develop a model which might able to make the energy consumption more economical and hence a more efficient wireless LAN (WLAN) structure.

Keyword:Bluetooth, WiFi, WLAN

Introduction:

In this paper we analyze average energy consumption of Bluetooth, WiFi (802.11) and cellular networks for transmitting data produced at f bytes per second. It is assumed that a packet is created every t_{buf} seconds and sent to the respective module for transmission. Thus, data produced by an application in t_{buf} is given by $d = t_{buf} * f$ bytes, neglecting packet overhead. The experiments are carried out by simulating various wireless devices and initiating the energy model to measure the energy consumptions. We also made WLAN model with real wireless devices and recorded the energy consumption with the standard watt-meter in standard wireless environment. After getting the actual scenario of energy consumption of wireless network we tried to develop a model which might able to make the energy consumption more economical and hence a more efficient wireless LAN structure.

Methodology:

With device-1(Bluetooth)

We consider a BlueCore2 Bluetooth module from CSR. The goal is to analyze power consumption of the module in its low power sniff modes with 40ms, 470ms and 1.28s sniff intervals (T_{sniff}). It is assumed to be in slave mode, with an ACL connection to a master. These settings are typically used in a standard Bluetooth Serial Port Profile. The current consumption values for 40ms and 1.28s intervals are taken from the data sheet, while the values for 470ms interval were provided by AliveTec Inc., which use this module in their wireless heart monitors consisting of an ECG sensor and a 3-axis accelerometer. Thus, it is important to note that this analysis can be easily applied to BlueCore3 module as well, but only for the 40ms and 1.28s intervals with appropriate values.. The T_{sniff} interval also determines the latency for data reception at the master.

The configuration of the device containing the Bluetooth module is assumed as follows: An MSP430 microcontroller sampling the sensors using its internal ADC, and sending a packet to the connected Bluetooth module every tbuf seconds. The parameter tbuf is chosen so as to allow the microcontroller to sleep while enough data is collected to form a single Bluetooth DH1, DH3 or DH5 packet. This configuration is similar to the heart monitor from AliveTec. The MSP430 can set up its DMA to do the sampling, while its core sleeps till the data buffer is ready in its RAM. The device operates at V = 3.7

volts.

Power Consumption Model

The Bluetooth slave module operates as follows in its sniff mode with ACL connection to a master: It is in sleep mode by default. It wakes up every Tsniff time to listen to the master and transmit all data from its buffer. It consumes IACL,active during this transmission, and IACL,connection while asleep and connected to the master.

Total data collected by the Bluetooth module in T_{sniff} interval is

$$D_{sniff} = d * (T_{sniff} / t_{sniff}) \text{ bytes}$$

Time to transmit D_{sniff} at b kbps is

$$t_b = 8*D_{sniff}/(b*1024) = (8f * T_{sniff})/(b * 1024) \text{ second}$$

$$Power = V * (I_{ACL,active} * tb + I_{ACL,connection} * (T_{sniff} – t_b))/ T_{sniff} \text{ Watts}$$

$$Power = V * (I_{ACL,active} - I_{ACL,connection}) * t_b + I_{ACL,connection} * T_{sniff})/ T_{sniff} \text{ Watts}$$

Specific Models

For an ACL connection in Bluetooth, 3 different packet formats are possible – DH1, DH3 and DH5 –each having a different packet length, thus providing varying bandwidth to the application. Table-1 gives packet lengths and maximum possible bandwidths corresponding to each packet type. For power calculations, we use these values to get the lowest possible power consumption for that configuration.

Packet Type	Packet Size (data bytes)	Bandwidth (kbps)
DH1 (1 slot)	28	172.8
DH3 (3 slots)	183	585
DH5 (5 slots)	341	733.9

Table 1: Bluetooth packet types for an ACL connection

We consider each sniff interval for our analysis, and further divide it according to the packet type (or bandwidth) desired by the application. Table 2 lists current consumption values for each Tsniff interval.

Sniff Interval (T_{sniff}) (ms)	$I_{ACL,connection}$ (mA)	$I_{ACL,active}$ (mA)
40	4.0	50.0
470	2.5	50.0
1280	0.5	50.0

Table 2: Current consumption values for different sniff intervals

From tables 1 and 2, and the power consumption model described above, we get the following models for each sniff interval.

Sniff Interval (Tsniff)	Packet Type	Power Consumption in terms of f (mW)
40ms	DH1	0.0077*f + 14.8
	DH3	0.0022*f + 14.8
	DH5	0.0018*f + 14.8
470ms	DH1	0.0080*f + 9.25
	DH3	0.0023*f + 9.25
	DH5	0.0019*f + 9.25
1.28s	DH1	0.0083*f + 1.85
	DH3	0.0024*f + 1.85
	DH5	0.0020*f + 1.25

Table 3: Power consumption models for Bluetooth low power sniff modes

Observation:

Next, we analyze the above models at different data production rates – 75, 100, 150, 300, 600 and 1200 Hz. We observe that for a fixed data production rate, increasing the sniff interval causes a proportionate decrease in power consumption. But, for a fixed sniff interval, decreasing data production rate does not cause a considerable decrease in power consumption. The comparison is shown in table 4 and figure 1.

Sniff Interval (Tsniff)	Packet Type	**Data Production Rate**(bytes per second)					
		75	**100**	**150**	**300**	**600**	**1200**
		Power Consumption (mW)					
40ms	DH1	15.3775	15.5700	15.9550	17.1100	19.4200	24.0400
	DH3	14.6950	15.0200	15.1300	15.4600	16.1200	17.4400
	DH5	14.9350	14.9800	15.0700	15.3400	15.8800	16.9600
470ms	DH1	9.8500	10.0500	10.4500	11.6500	14.0500	18.8500
	DH3	9.4225	9.4800	9.5950	9.9400	10.6300	12.0100
	DH5	9.3925	9.4400	9.53500	9.8200	10.3900	11.5300
1.28s	DH1	2.4725	2.6800	3.0950	4.3400	6.8300	11.8100
	DH3	2.0300	2.0900	2.2100	2.5700	3.2900	4.7300
	DH5	2.0000	2.0500	2.1500	2.4500	3.0500	4.2500

Table 4: Power consumption values for specific data production rates for all sniff modes and packet types

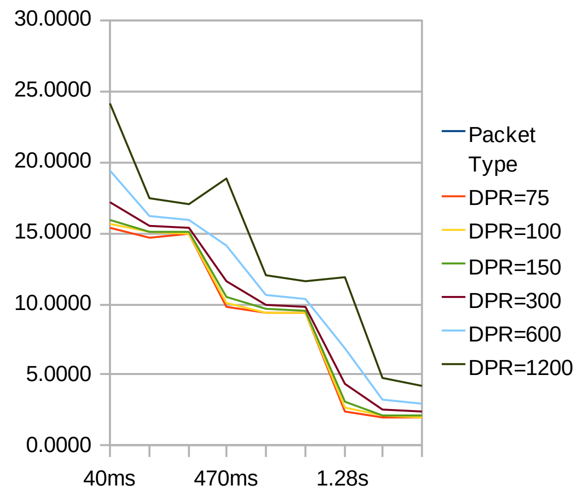

Fig-1: Power consumption values for specific data production rates for all sniff modes and packet types

With device-2 (WiFi)

WiFi radios have a high wakeup and connection maintenance energy, but low energy per bit transmission cost and high bandwidth. It is observed that if the WiFi module is left on for more than 15 sec, it is more efficient to shut it down. Thus, we break up our analysis into two parts: for transmission intervals ($T_{transmission}$) less than 15 sec, and those greater than 15 sec. For simplicity, the time taken to transfer data (O(ms)) after each interval is assumed to be negligible as compared to the transmission interval (O(sec)).

Total data collected by the WiFi module in $T_{transmission}$ interval is

$$D_{transmission} = d * (T_{transmission} / t_{buf}) \text{ bytes}$$

Energy to transmit Dtrans bytes at 7 J/MB is

$$E_{transmission} = D_{transmission} * 7/(1024 * 1024) \text{ J}$$

Energy required to maintain the connection for $T_{transmission}$ time at 19 J/min is

$$E_{maintain} = 19 * T_{transmission}/60 \text{ J}$$

Energy required to establish the connection is

$$E_{establish} = 5 \text{ J}$$

$T_{transmission}$ Interval	**Power Consumption** (mW)
$T_{transmission}$ <= 15 secs	$(E_{transmission} + E_{maintain}) / T_{transmission} = 7000*f/(1024*1024) + 19000/60$ $= 0.0067*f + 316.67$
$T_{transmission}$ > 15 secs	$(E_{establish} + E_{transmission}) / T_{transmission} = 5000/ T_{transmission} + 7000*f/(1024*1024)$ $= 5000/ T_{transmission} + 0.0067*f$

Table 5: Power consumption models for different transmission intervals for a WiFi radio

$\mathbf{T_{transmission}}$ **(sec)**	**Data Production Rate** (bytes/sec)					
	75	**100**	**150**	**300**	**600**	**1200**
	Power Consumption (mW)					
$T_{transmission}$ <=15	317.1725	317.34	317.675	318.68	320.69	324.71
30	167.1692	167.3367	167.6717	168.6767	170.6867	174.7067
60	83.83583	84.00333	84.33833	85.34333	87.35333	91.37333
120	42.16917	42.33667	42.67167	43.67667	45.68667	49.70667
300	17.16917	17.33667	17.67167	18.67667	20.68667	24.70667
600	8.835833	9.003333	9.338333	10.34333	12.35333	16.37333
1200	4.669167	4.836667	5.171667	6.176667	8.186667	12.20667

Table 6: Power consumption of a WiFi radio at different data production rates and different transmission intervals

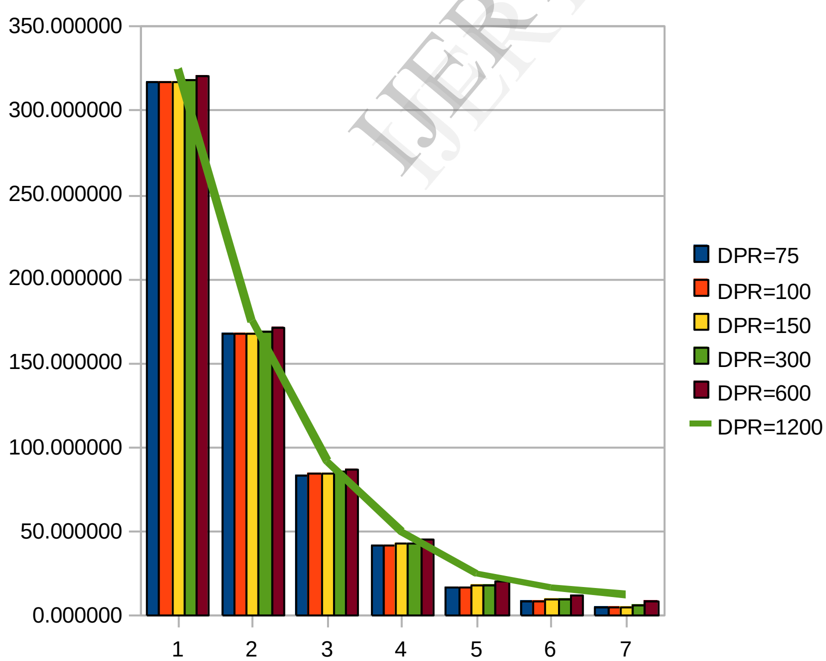

Fig-2: Power consumption of a WiFi radio at different data production rates and different transmission intervals

Conclusion:

In the above analysis it is observed that for a fixed data production rate, increasing the sniff interval causes a proportionate decrease in power consumption. But, for a fixed sniff interval, decreasing data production rate does not cause a considerable decrease in power consumption. WiFi radios have a high wakeup and connection maintenance energy, but low energy per bit transmission cost and high bandwidth. It is observed that if the WiFi module is left on for more than 15 sec, it is more efficient to shut it down.

Future Work:

With this line of thinking many other wireless devices can analyzed for their efficiencies of energy consumption. Also with simulation technique there are so many ways to model any scenario of wireless networking structure and analyze them for getting some useful results in this important field. Simulators like MATLAB-Simulink, NS2, NetSim, Glomosim, OPNET, NS3 etc can be used for simulate any situation of wireless networks for getting adequate research data for further development.

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