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EVALUATION OF POWER EFFICIENCY IN WIRELESS SENSOR NETWORKS USING MATHEMATICAL OPERATIONS

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Abstract

With the advances on semiconductor technologies, wireless communication applications are an emerging class of applications on battery powered devices. Estimating the power consumption and computational complexity of various digital signal processing (DSP) algorithms used in wireless communications systems is critical to assess the feasibility of implementing such algorithms in hardware, and for designing energy-constrained communications systems. In this paper different mathematical operations are performed to analyse the power at different frequencies. The developed approach is used to evaluate the computational power of several DSP algorithms used in wireless communications systems, and perform thorough computational complexity comparisons. The power consumption evaluation of the considered DSP algorithms show that some algorithms may require a prohibitively high power, which makes such algorithms unsuitable for power constrained wireless communications systems. The power is measured for OFDM and FBMC system for various clock frequencies. The results also show that the proposed methodology can be adopted for various hardware implementation, however, some calibration might be required based on the adopted platform. The performance of the system is evaluated using matlab tool.

Keywords

OFDM, FBMC, Power Efficiency, Digital Signal Processing

1. Introduction

Power optimization to enhance the battery life-time is one of the most vital challenges for several emerging technologies, particularly wireless communications networks where the demand for high speed mobile data access is rapidly increasing. At the transmitter side, achieving high data rate transmission requires deployment of higher order modulation schemes to save the limited and expensive bandwidth resources [1]. Hence, these schemes require more power to be allocated for each transmitted bit. At the receiver side, majority of receivers are designed with capability to operate at very low signal-to-noise-ratio (SNR) using advanced receiver architecture which typically requires a considerable number of signal processing operations has to be performed in such receivers [2]. Consequently, the transceiver will be under a bidirectional high-power consumption due to the high order modulation schemes at the transmitter, and the high number of signal processing operations at the receiver. Consequently, battery supplied wireless devices will suffer from poor quality of experience (QoE) due to the limited available power while most wireless applications are becoming more power-demanding [3]. The power consumption in any communications device is divided into two main categories, transmitting-receiving power and processing power. In the past, processing power didn't capture much attention because it was considered negligible as compared to the transmission power. However, with the emerge of wireless sensor networks (WSNs), Internet of Things (IoT) [4] and device-to-device (D2D) communications [5], the processing power may become non-negligible due to the massive number of required operations, while the transmitting power could be low due to the short distance between such devices. Moreover, low power networks can be constructed using peer-to-peer communications where the deployment of a central node or a base station is not required and hence, the computational power of the arithmetic logic unit (ALU) in the central processing unit (CPU) [6] becomes an important component in the device power budget.

Research on battery-efficient system design has largely been motivated by the need to improve battery lifetime, but it has mainly focused on minimizing average power consumption. However, recent research has established that minimizing average power does not necessarily translate to maximizing battery life. This is because, in practice, the amount of energy delivered by a battery can vary significantly, depending on the time profile of the current drawn from the battery [7]. Therefore, power profiling techniques should be used in order to optimize power consumption of different applications. Furthermore, in order to obtain power-efficient mobile systems, the application level of the system should be designed for low power consumption [8]. The main idea of power-aware applications is that they should adapt and take corrective measures during their execution in order to optimize energy consumption and use resources efficiently.

On the other way, today's popular IEEE 802.11 standard for wireless networks has changed the face of networking. WLAN market has grown rapidly as wireless technology has evolved to meet fundamental needs of businesses and technology consumers. Wireless links have intrinsic characteristics (variable bandwidth, corruption, channel allocation delays) which influence the performance of transport protocols but also the energy consumption of battery powered devices. In this paper we present our results of the wireless communication power efficiency study and estimating the power consumption and computational complexity of various digital signal processing (DSP) algorithms used in wireless communications. We give first a summary on existing advances in wireless power efficiency analysis and measurements and then present the evaluation application and the obtained results. The results are evaluated at different frequency using different number of mathematical operations.

2. Related Work

One very popular application on a battery powered mobile devices is multimedia content visualization over a wireless link. The authors in [9] evaluate the impact on three encoding parameters on the CPU cycles during the decoding process. A total cost in terms of CPU cycles is introduced and a relationship to power consumption is suggested, but power consumption measurements are not performed, thus the cost model cannot be verified in practice. A fine grained benchmark with a low power wireless mobile computing platform (Consus) was conducted in [10] where Bluetooth and Wi-Fi components are compared. Although their power profile looks similar, the power consumption of the radio Wi-Fi component represents 60% of the total power. This identifies the radio subsystem as a primary candidate for specific power management optimizations.

A more generic approach towards application-level prediction of power consumption and battery dissipation has been taken in [11], where an estimation methodology is introduced. Based on a set of drain-rate curves from a set of benchmarks, estimation for an arbitrary program is composed. The estimation is limited to CPU and memory dimensions and it does not take into account the display, wireless communication or I/O components, but could be extended to include wireless basic benchmarks to assess wireless based communication applications. One of the implications of the application move towards unified communication systems is that most of them require secure communications that are provided through cryptographic components realized in both hardware and software. As one might suspect, there should be a link between security protocols and energy consumption on battery powered embedded systems. The authors of [12] have conducted thorough measurements and proved that security processing has a significant impact on battery life. They have conducted an energy consumption analysis on a wide set cryptographic algorithm, including a thorough analysis on the SSL protocol, where its energy consumption is broken into cryptographic and non-cryptographic components.

Some proof on the increased usage of wireless mobile devices has been reported in [13], where wireless data transfer and battery lifetime for Wi-Fi connected mobile terminals has been logged in several networks in the US.

3. Methodology

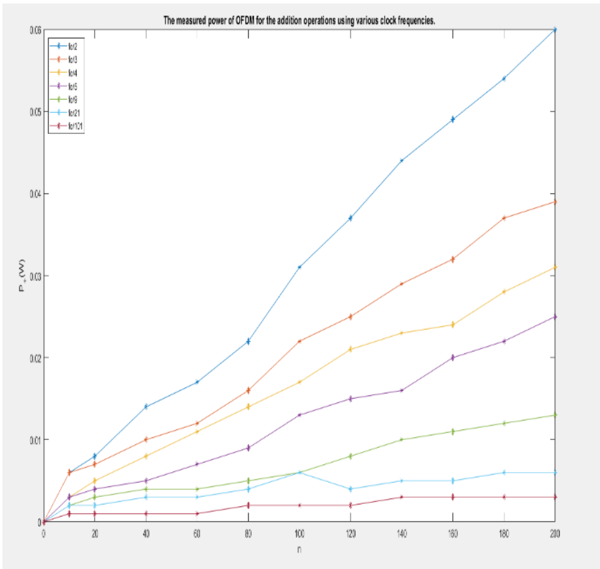
In this work, the power required for performing various operations in digital signal processing is shown. In DSP the main mathematical operations are addition, subtraction, division, multiplication and discrete fourier transform (DFT). Without these operations many of the wireless communications will not work or process. For evaluating the power consumption the following formulas are considered and processed.

A. Addition

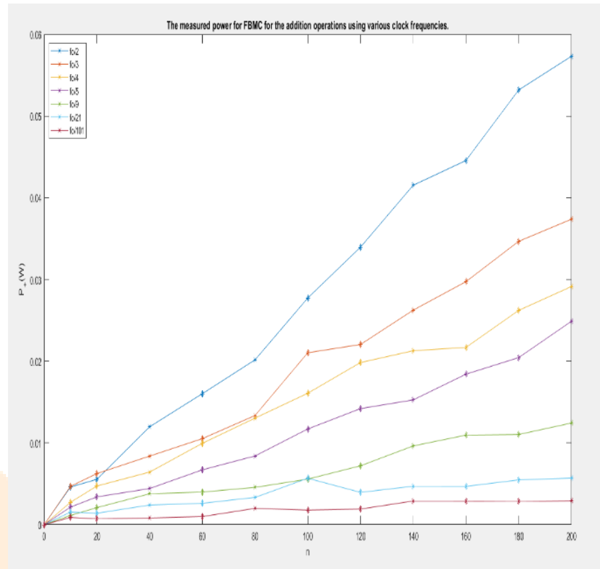
Fig 1(a) and 1(b) shows the measured power needed for the addition operation. As can be noted from the figure, the power changes linearly versus n and f, and the fitting polynomial can be expressed as

$$P+=(a_1 n+a_2)f \qquad (1)$$

where the polynomial coefficients are a_1 = 5.258×10^{-6} and a_2= 1.223 × 10^{-4}. Generally speaking, the values of $P+$ are small, however they are non-negligible for large values of n and f.



(a)



(b)

Fig1. Power measure for OFDM and FBMC system using addition operation

As it can be noted from the figure, the minimum value of f used is $f_0/101$, using lower f values makes it difficult for the power analyzer to detect the power difference when the number of additions is varied. Generally speaking, the values of P+ are small, however they are non-negligible for large values of n and f.

B. Subtraction

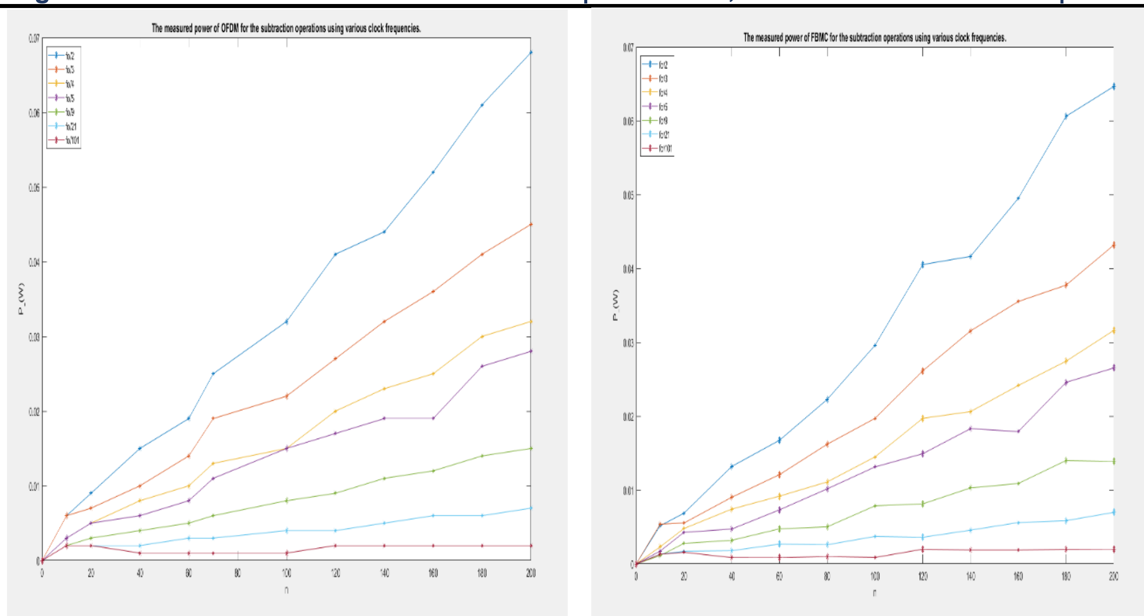
The power required for the subtraction operation is depicted in Fig. 2(a) and 2(b), and the fitting polynomial is given by

$$P-=(a_1 n+a_2)f \qquad (2)$$

where the polynomial coefficients are, $a1$ = 6.6×10^{-6} and $a2$ = 3 ×10^{-5}. To compare the power for the addition and subtraction operation, we compute the relative average power for both operations using (1) and (2) for large values of n, which can be expressed as

$$\eta+-=\frac{lim_{n\to\infty}P-}{lim_{n\to\infty}P+} \qquad (3)$$

Therefore, η+− = 6.6×10−6/5.258×10−6 = 1.25. As can be noted form the result, subtraction requires some additional power as compared to addition.



(a) (b)

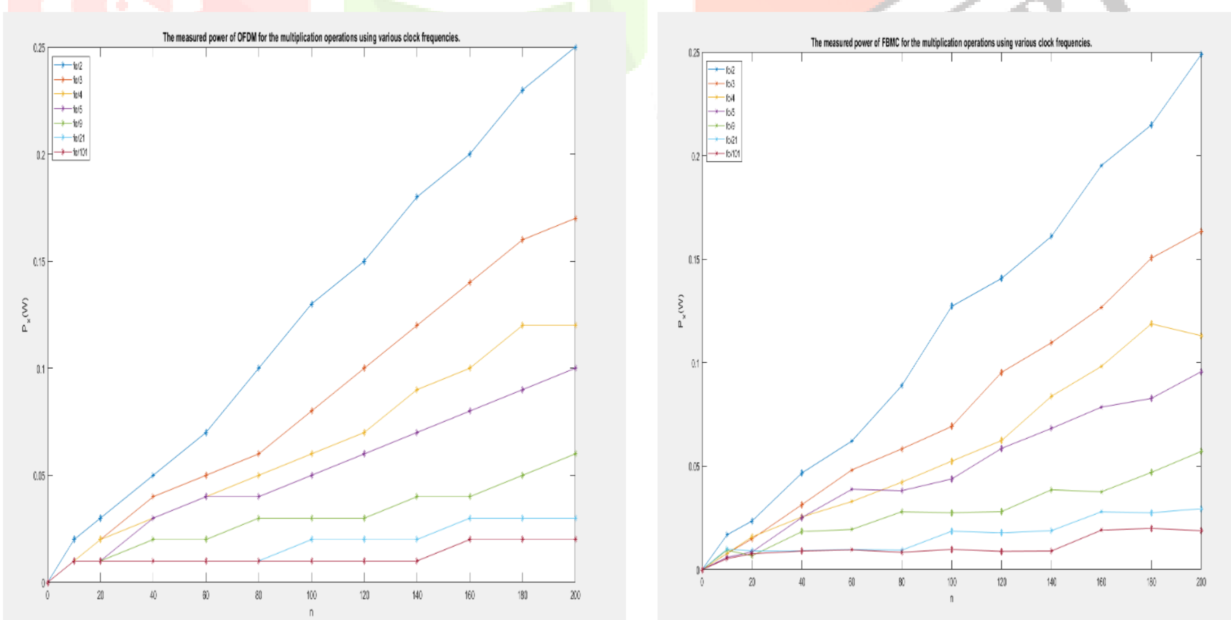
Fig2. Power measure for OFDM and FBMC system using subtraction operation

C. Multiplication

The power measurements associated with the multiplication operation are depicted in Fig 3(a) and 3(b), and the fitting polynomial is given by,

$$P_\times = (a_1 n + a_2) f \qquad (4)$$

where $a1 = 2.578\times10^{-5}$ and $a2 = 4\times10^{-5}$. Therefore, the power required for multiplication has linear tendency as well, and for large values of n, the relative average power $\eta_{\times+} = 2.578\times10^{-5}/5.258\times10^{-6} = 4.903$, which is computed using (3) except that P_- is replaced by $P_\times$.



(a) (b)

Fig3. Power measure for OFDM and FBMC system using Multiplication operation

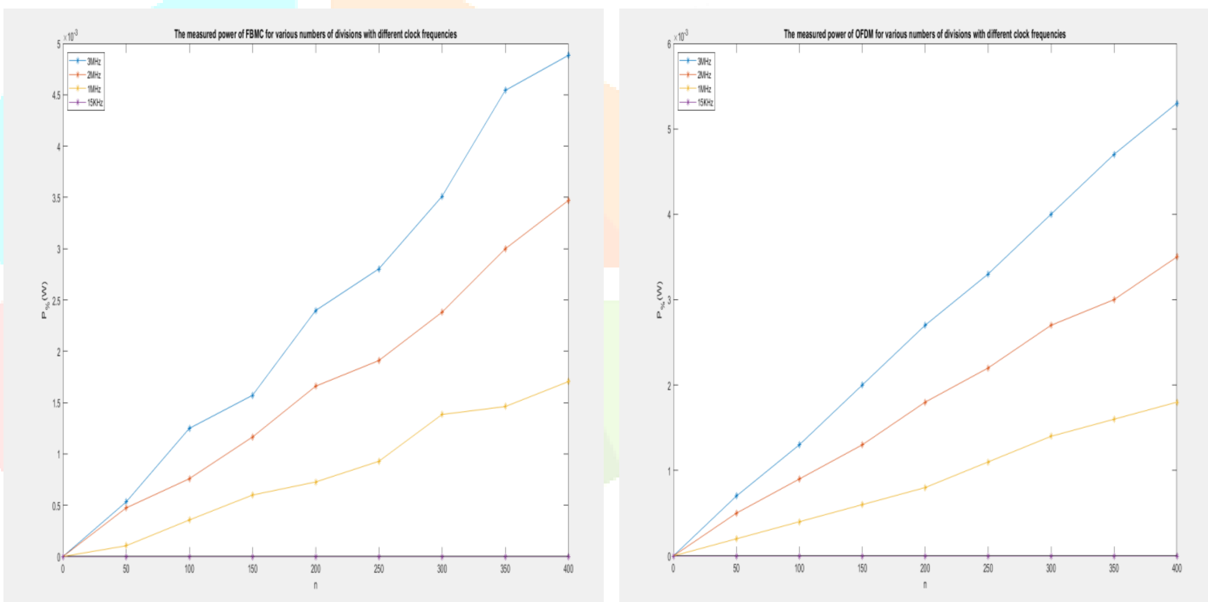
D. Division

The measurements' results of the division operation are given in Fig 4(a) and 4(b). The figure also shows polynomial fitting, where the polynomial with the minimum RMSE is given by

$$P \div = a_1 n + a_2 f \tag{5}$$

where a_1 = 8.114$\times 10^{-4}$ and a_2 = 4.921$\times 10^{-3}$. As it can be noted from the figure, the division operation power changes linearly versus n and f and it is substantially larger than all other operations.

The obtained measurements show that the addition and division operations are linearly proportional to the number of operations n and the clock frequency f. On the other hand, the subtraction and multiplication exhibited some nonlinearity in terms of n. However, the nonlinear term is generally small and the power changes almost linearly as a function of n and f.



(a) (b)

Fig4. Power measure for OFDM and FBMC system using Division operation

4. Conclusion

In this paper, we presented a novel metric to evaluate and compare the computational complexity of various baseband signal processing algorithms in wireless communications systems. The proposed metric is based on mapping the computational complexity of an algorithm to the computational power. Therefore, the total computational power can be computed and presented into a single metric, which makes the comparison between different algorithms simpler and more informative. The work is based on an extensive measurements campaign conducted to evaluate the computational power at the fundamental operation level, and hence, the total computational power can be computed accordingly. The developed model implies that, on average, the division process is the most power hungry operation with a computational power that is about 222 times the power for the addition operation, the multiplication was less power-demanding where a single multiplication operation is equivalent to four additions, and the subtraction is comparable to the addition where a single subtraction is about 1.1 times of the addition. The new metric was used to evaluate the total computational power for PAPR reduction, CFO and channel estimation techniques. From the overall results it is clear that OFDM requires larger power when compared to FBMC system.

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