Power Switching Energy Management Technique in Multichannel Industrial Wireless Sensor Nodes

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Abstract—**This paper presents sensor input channel power switching as an energy saving technique for the extension of lifespan in multichannel industrial sensor node development. Industrial sensor nodes are usually attached to machines and processes with more than one parameter measurement at a time when deployed. Industrial multichannel sensor node energy drains much faster as compared to conventional nodes and therefore requires other power management techniques other than the Active-Idle-Sleep mode process in use with other types of nodes. This paper presents a switch to deep sleep (OFF) mode as addition to effective energy usage by unintelligent components in a sensor node. The resultant Active-Idle-Sleep-Deep sleep mode process can be implemented in any or a combination of the developed power management algorithms as a request based, event based, or time based power distribution technique.**

Keywords—Multichannel, Switching, Sensor Node, Design Issues, Algorithm

I. INTRODUCTION

Wireless sensor networks (WSN) are composed of sensor nodes which are in themselves small electronics circuits capable of sensing parameters, conditioning sensed signals, processing data, storing data, and communicating with other nodes or data terminals. These sensor nodes are rapidly finding their way into data acquisition in many industrial settings [1]. However, the development and deployment of these electronic nodes is faced with several challenges [2] among which the most dreaded is its life time. The life time of a sensor node defines how long the node will remain actively used for the purpose of its deployment. Several factors affect the life span of a node ranging from design to deployment issues. Due to the independent and solitary nature of nodes in most applications, sensor nodes are most probably powered by independent energy sources [3] mostly batteries. Of course, battery has a finite amount of energy to be delivered to a connected load. This therefore means that a sensor node powered by a battery no matter how well designed [4], will die once the battery is totally exhausted. To elongate the node's life span therefore, a number of issues must be addressed which revolve around energy management within the node and the network in which it is deployed. These issues involves design methods [5], mode of operation, processing power of the node, communication overhead, power source type, etc. However, at design time several of these factors must be considered as guide to the selection of components for node development as well as node selection for a network deployment.

Industrial sensor nodes are most likely to multichannel systems developed as single nodes with more than one sensor device for the acquisition of several parameters from a single point. With the number of sensor devices to be powered, a more stringent power management technique becomes more desirable, otherwise the node dies off in much shorter time than expected. This paper presents a switching technique for sensor power management within a multichannel sensor node. Issues surrounding battery selection for industrial sensor nodes are also discussed.

A. Research Background

Generally, energy issue is major point of interest when sensor nodes are to be deployed for monitoring and control. The energy demands worsen when batteries must be used and much further when multichannel sensor nodes which are typical of most industries are being deployed. Battery powered systems could be quite expensive to maintain when poorly designed such that the batteries are replaced much often. This results to high running cost which is a reflection high energy demand by the nodes, and does not fit to the low-cost needs of today's industry. Hence, there is much need for search of new platform and algorithm for energy management in future multichannel industrial nodes. In order to attend to this drawback, this paper takes a look at the structure of typical sensor nodes and investigates the energy demand of component parts as a pointer to the provision of hardware platform and software algorithm for industrial multichannel sensor nodes development.

II. ENERGY ISSUES IN SENSOR NODES

WSNs are usually intended for high data availability at low-cost and at all times. This however is greatly dependent on the life time of nodes used in the network. The life time of the node, on the other hand, depends on how much it could operate within its energy limit. Several literatures have been published with regards to energy usage and management in sensor nodes and networks. Chulsung et al [6] considered the extension of battery life as the main objective in the design of an energy-efficient WSN. Their work looks at the impact of the nodes transmission power level, sampling interval, transmission time, and ambient temperature on its battery discharge characteristics. In [7][4] several power saving and energy optimization techniques in a WSN were discussed. The work x-rays issues on hardware design, transmission energy, and routing protocols as causes of energy loss in wireless sensor nodes and power wastages in a WSN. The energy demand of a sensor node has a serious implication on the cost of a network in which it is being used. Since applications deploying sensor nodes for industrial data acquisition are doing so due to low cost offer of WSNs, sensor node characteristics must be exploited towards cost reduction for industrial satisfaction. The node power characteristics are embedded in the structure of the node as depicted in Fig. 1. Each stage of the structure demands a careful consideration both in design and choice of components. However, for industrial sensor nodes the sensing element and its accompanying signal conditioning stage could be very demanding in energy usage [8]. The high energy demand is usually due to the nature (size, ruggedness) of sensors required for parameter sensing in the noisy industrial floor. Although, several works have pointed out the power demand of radio devices (transmit and receive power) [9, 10, 11] used in sensor nodes, few has consider the effect of power consumed in running multiple sensing element with diverse characteristics on the battery. Majorly, the radio, sensing element and the signal conditioning are unintelligent and are not friendly to the power source. Energy management therefore demands that intelligence be built in the node to control the use of power by these components. Hence, a number of works have tailored towards switching the sensor node between its active mode and sleep mode [9]. This however has some effect on the reliability of the network.

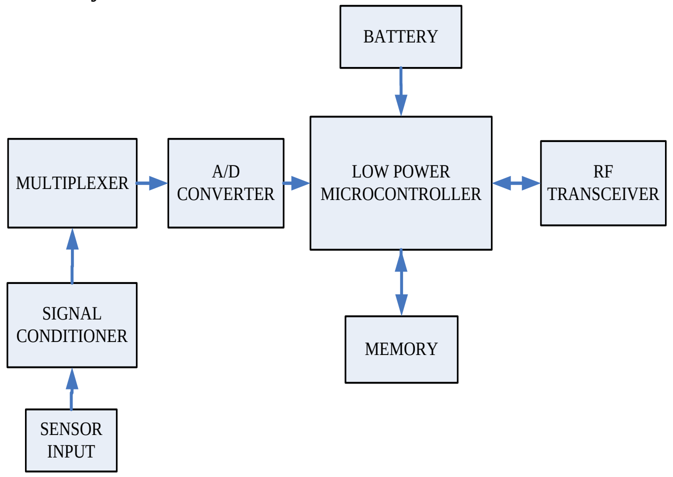

Figure 1: Sensor Node

III. MULTICHANNEL SENSOR NODES

Industrial sensor nodes are generally made to attach to machines and processes; hence they are likely to sense more than one parameter when deployed. This then means that a number of sensing elements may be connected to the node's input terminals as desired. Industrial sensors are usually of more rugged characteristics due to the nature of the industrial floor. Their energy demand could be very high and they are usually slow in response. Powering a number of these sensors all the time from a battery source places a fast drain on the battery. On the other hand, using "selective power on demand" process may introduce much latency as a result of slow response. For applications where latency could be tolerated, selective power switching can be efficiently used to save power. In non-real-time industrial applications where the resultant control point is a statistical mean, latency introduce by these sensors could usually be determined before hand and use to set the data acquisition time. Therefore multichannel sensor nodes are much suitable for statistical industrial applications and can be developed for a long life span with selective power switching.

A. Energy Usage in Different Operating Modes

Sensor nodes are operated in different power utilization modes as a method of energy conservation within the node and the entire network. The available modes are: active mode (when the node is busy sensing, processing and communicating), idle mode (when the node is ON but not busy), sleep mode (when the node is apparently OFF but still listening to incoming signals) and deep sleep mode (when the node radio and sensing elements are totally OFF and its processing unit in sleep mode). In today's chip manufacturing technologies, all of these modes can be built into any of the components of a sensor node. This makes it possible for designers to achieve different energy saving options within a node. Fig. 2 shows a chart of operational modes of components in an 8-channel industrial sensor node using PIC18F2620 (microprocessor), KYL500S (transceiver), LM324 (signal conditioning), and 2981 8-channel source driver chip as power distributor. As shown in figure 2, no energy is dissipated when node components operate in OFF mode (in deep sleep), and the least energy is consumed when components operate in their sleep mode. The highest amount of energy is consumed when nodes are active and for efficient power conservation, components must spend less time in their active mode.

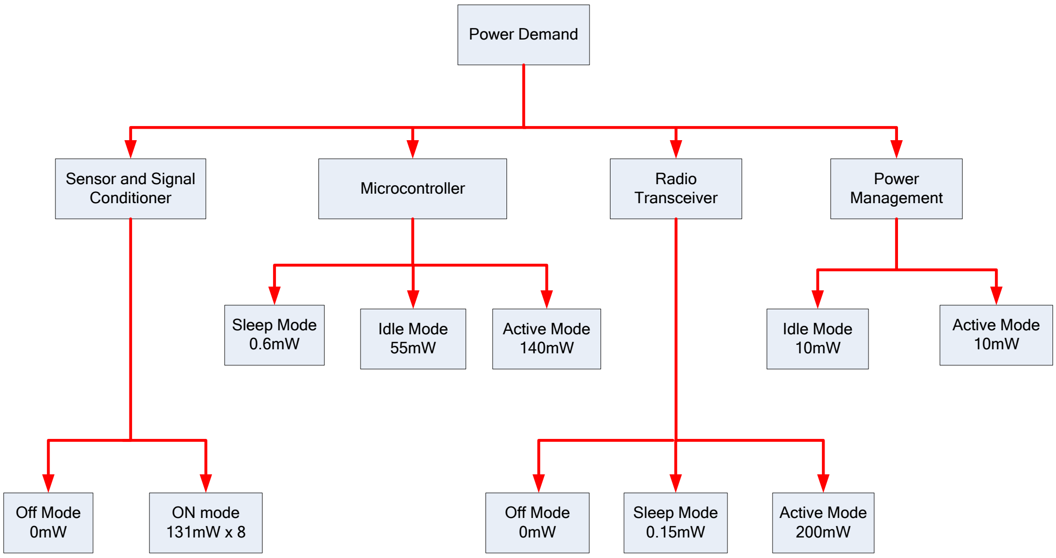

Figure 2: Power Demand Chart of a Typical Node

B. Hardware Design Issues

The design of sensor node hardware needs a careful thought due to its energy constraint. Each unit within the node consumes a characteristic amount of energy that must be used to carry out its functions. However, the hardware design should be tailored toward the reduction of energy usage by these units in order to increase life span. This consideration posses more challenges in multichannel industrial node designs where a number of sensor elements with diverse characteristics are used. One of the major ways to reduce power usage in a multichannel node is signal multiplexing such that sensors outputs are sampled one at a time. This helps to reduce component count by employing only one ADC for any number of sensors used. As shown in Fig. 3, the sampling is address based and is therefore flexible enough for any sensor channel to be selected at anytime. However, this scheme is implemented today in several microcontrollers, which makes it possible to further reduce power in hardware design.

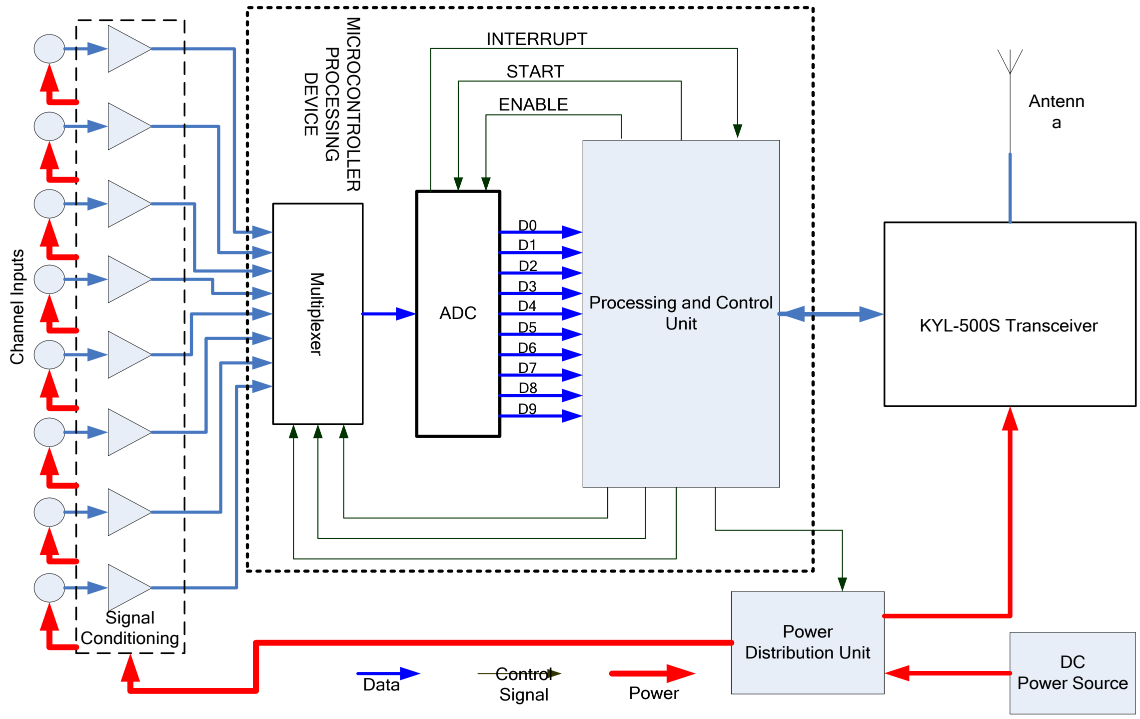

Figure 3: A Multichannel Sensor Node Hardware Design Consideration

Multiplexing does not reduce the energy consumed by the sensors themselves. With all sensors left ON all the time, much energy demand will be placed on the source and the node will die sooner than desired. It is therefore a good practice to use a power management process such that will ensure energy conservation. One could schedule power distribution to the sensors and other energy consuming components such as the radio say, on timely bases or on demand bases. Sensing components with high response time should be put OFF all the time and powered only on demand. Slow response sensing devices that requires much energy to keep them active should be timed and powered ON for a time equal to their response time before they are sampled. However, slow response sensing devices which consumes huge amount of energy at start-ups but requires a little power to keep them active are not desirable to be powered ON-OFF all the time as this may have much energy demand on the source.

The radio consumes a considerable amount of energy in the node especially when active. Most designers therefore operate the radio in its sleep mode most of the time where it consumes less. In applications where latency is not stringent, the radio could even be operated in its deep sleep (OFF) mode. The wake-up time of the radio could then be scheduled by the controlling unit. This could also be the case when the network is event driven rather than by request, such that the radio is required to transmit data only at the occurrence of certain events. Furthermore, the microcontroller carrying out the control and data processing must be kept alive enough as to be able to listen to events whenever they occur. The microcontroller could be operated in its sleep mode at no-event period in order to conserve more energy.

IV. CHANNEL POWER SWITCHING

This paper considers power switching to sensing devices as an energy saving technique in industrial multichannel sensor node development. As shown in Fig. 4, power to each sensor and its signal conditioning unit is controlled from the microcontroller based on a scheduled scheme. The scheme is based on activity timing, occurrence of some events, and request for data acquisition. Industrial activities are not usually uniform; at sometimes they are high and can be very low or even completely closed down at other times. Most of these activities can be predetermined and could therefore be timed. This means that nodes should be made to utilize low activity and closed down times to save energy by switching OFF most of its components and use timing to predict when to reactivate. When timing is used, all sensing devices are made to switch OFF and assuming requests are not expected, the radio can also be switched OFF. The node would therefore operate at its minimum energy demand with the processing unit operating in its sleep mode. Again, some processes are event driven and needs urgent attention when such events occur. The scheme must therefore assign higher priorities to such processes by maintaining power supply to the required channels within the node while other channels are powered down and sampled only at intervals or when needed. When event driven conditions are implemented, the radio can be switched OFF (deep sleep mode) completely if delays are tolerable else the radio is operated in its sleep mode. The degree of latency acceptable should however be checked with the wake-up time of the radio and processing unit.

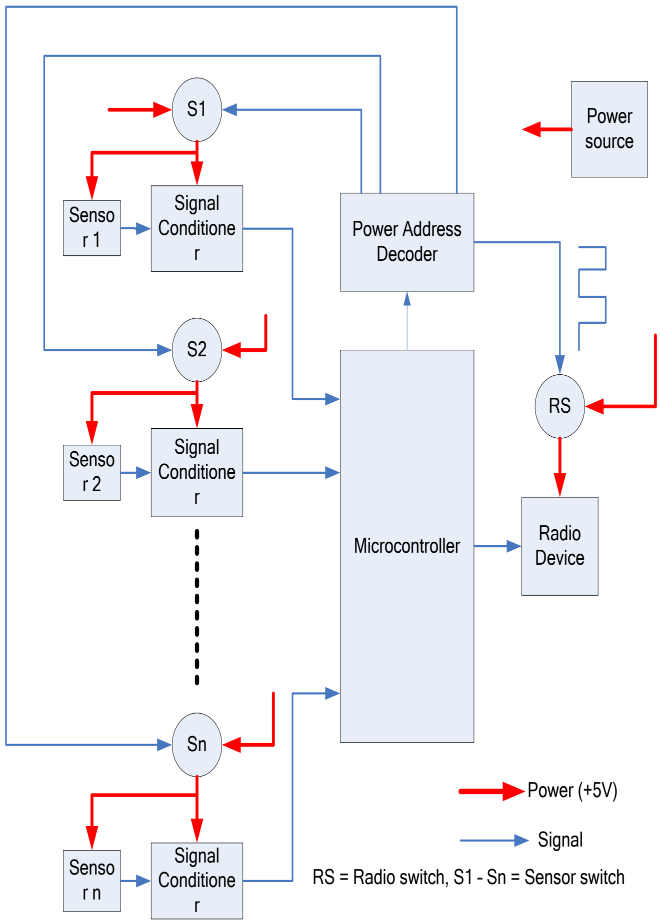

Figure 4: Channel Switching Power Distribution

Furthermore, data acquisition could be based on request from a host device. This requires the radio device to be at most operated in its sleep mode where it can listen to incoming request signals. Therefore, channels could be completely switched OFF for energy conservation at none active times.

Hence, if there are n number of sensors attached per channel to the node, each sensor device will be operating in its active mode a, idle mode i, sleep mode s or OFF mode d at a given time. Therefore,

$n = Na + Ni + Ns + Nd$,

Where Na = number of active channels, Ni = number of idle channels, Ns = number of sleeping channels, Nd = number of channels powered down (OFF) and $Na = Ni = Ns = Nd = 1, 2, 3, ---$

Power demand by a channel at any given time t is $P = Pa + Pi + Ps + Pd$.

Therefore, total power demand by all channels is,

$$P_T = \sum_{a=0}^{Na} P_a + \sum_{i=0}^{Ni} P_i + \sum_{s=0}^{Ns} P_s + \sum_{d=0}^{Nd} P_d \text{ ------------------------(1)}$$

Energy consumed at the given time *t* is then,

$$E = \sum_{a=0}^{Na} P_a{\cdot}t + \sum_{i=0}^{Ni} P_i{\cdot}t + \sum_{s=0}^{Ns} P_s{\cdot}t + \sum_{d=0}^{Nd} P_d{\cdot}t \text{ -------------------(2)}$$

Since P_d is always zero, the higher the number of channels powered down *Nd*, the lesser the energy consumed at a given time. Hence, switching most channels off will reduce power demand to its minimum. At conditions where channel power down is not desirable, operating the channels in sleep mode and probably in idle mode will be more desirable since $Ps < Pi < Pa$.

Considering energy reduction through other devices mostly the radio, the control scheme can be done in such a way that every opportunity is harnessed toward energy reduction. Fig. 5 is a sample request based flowchart for energy management in a multichannel industrial node. Fig. 6 is an event driven based algorithm, while Fig. 7 is time based algorithm for industrial periodic data acquisition. In each of these algorithms, equation 2 could be effectively applied for energy conservation in the node.

In algorithm 1 (Fig. 5), the microcontroller and the radio are kept at sleep mode while other peripheral devices are completely powered down. The minimum energy consumed is therefore determined by the microcontroller and radio sleep mode power demand. Since the node may be sleeping most of the time, energy will be adequately conserved. In algorithm 2 (Fig. 6), the microcontroller operates in its sleep mode while event dependent channels operates in their active mode. Energy is conserved by switching OFF non-event dependent channels and the radio. Hence, the minimum energy demand depends on the number of event based channels in the node.

Algorithm 3 (Fig. 7) utilizes the least amount of energy in its power down time where only the microcontroller operates in its sleep mode with all other devices switched OFF. The node is made to schedule its active and non-active times based on the industrial activities in such a way that activities are timed for channels to be sampled for a period of time. At low activity times, only few channels may be switched ON and others powered down. As the industrial activities increases more channels could be switched ON. However, the time scheduling could be combined with either or both event driven and request based control for further energy conservation.

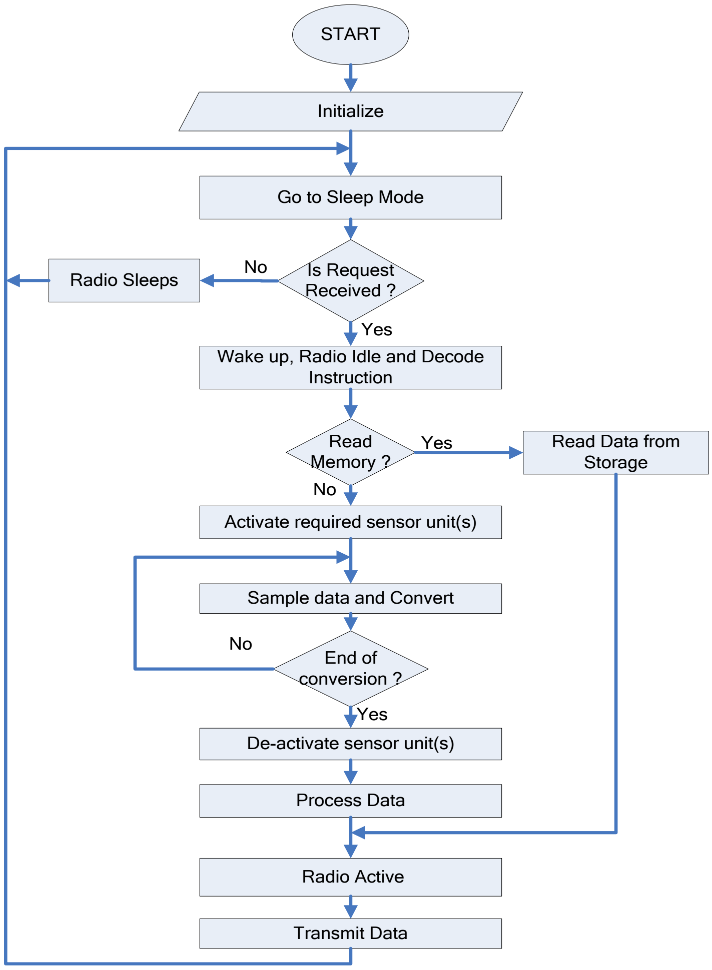

Figure 5: Request Based Algorithm

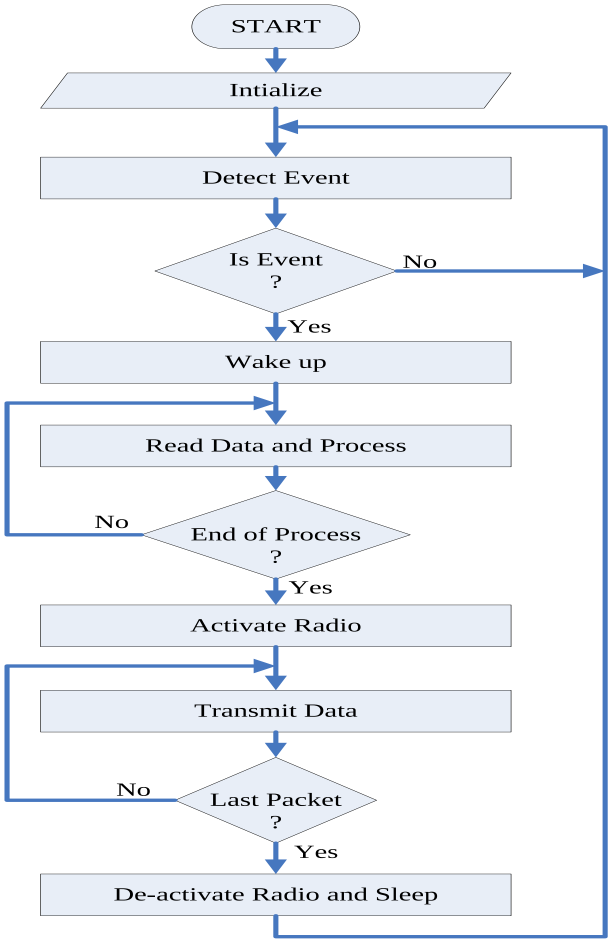

Figure 6: Event Based Algorithm

V. APPLICATION ISSUES IN POWER CONSIDERATION

Generally, different applications pose diverse stringencies on energy requirements and lifespan. Applications where the sensor node locations are indeterminate and therefore must be run to death, lifespan requirements are usually of high priority. Nodes deployed for such applications are more energy sensitive and are likely to be ran in their sleep mode and deep sleep mode most of the time especially when latencies can be tolerated. Examples of application in this category are military drone surveillance, hazardous environmental study, outer space studies. For applications where several nodes can be manually deployed but must be run to death before maintenance is carried out, lifespan considerations may be less stringent since the node locations are mapped in the network. Such applications are found in agricultural monitoring of crops. In industrial applications where the nodes are easily accessible, predictive maintenance in which single dying nodes can be targeted for battery replacement, lifespan stringencies are less strict especially when latency requirements are low.

However, sensor nodes and their networks should be targeted for low energy consumption and long lifespan. Using the necessary power plan and appropriate energy control and data transfer algorithms will ensure good lifespan and reduce energy demand which leads to low maintenance, high reliability, and low-cost.

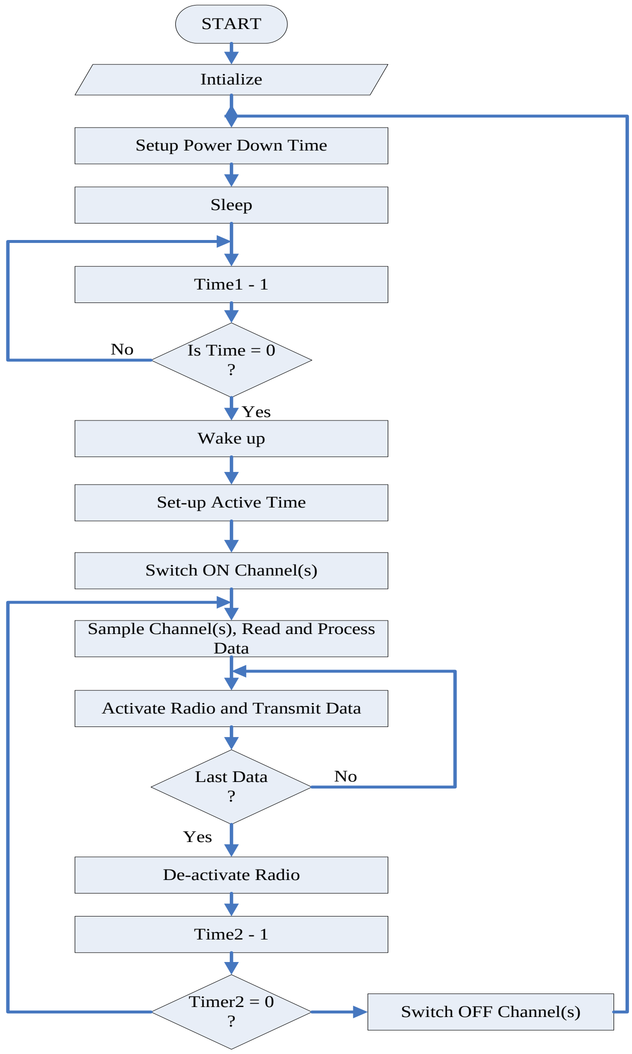

Figure 7: Time Based Algorithm

VI. CONCLUSION

In the development of industrial multichannel sensor nodes, power consumption can be quite high due to the different sensor characteristics and energy demand. Most industrial equipments/machines operating conditions are such that sensors used cannot be easily trimmed down and therefore must be powered at some high levels. Running these sensor elements on a continuous time basis poses serious energy problems to industrial multichannel sensor nodes development. The way out towards reducing energy usage in multichannel nodes and increase both node and network lifespan is by implementing an appropriate channel switching technique as presented in this paper. Selecting and adopting the needed switching algorithm or a combination of algorithms that give optimal results for an application is a role that must be adequately played at design time.

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