Aalborg Universitet

Adaptive Information Access in Multiple Applications Support Wireless Sensor Network

Tobgay, Sonam; Olsen, Rasmus Løvenstein; Prasad, Ramjee

Publication date:
2012

Document Version
Early version, also known as pre-print

Link to publication from Aalborg University

Adaptive Information Access on Multiple Applications Support Wireless Sensor Network

Sonam Tobgay*, Rasmus L. Olsen**, Ramjee Prasad*, IEEE Fellow

*Center for TeleInFrastruktur (CTiF)
**Networking and Security Section
Aalborg University, Department of Electronic Systems, Aalborg, Denmark
Email: {in_st, rlo, prasad} @es.aau.dk

Abstract— **Nowadays, due to wide applicability of Wireless Sensor Network (WSN) added by the low cost sensor devices, its popularity among the researchers and industrialists are very much visible. A substantial amount of works can be seen in the literature on WSN which are mainly focused on application specific WSN considering its resource constraints, neglecting the return-of-investment and usefulness of the system. In this paper, we bring out the WSN scenario which supports multiple applications and study the challenges that would pose in implementation as each specific application has its own specific set of requirements. Lastly, the paper suggests a mechanism by which the information access or acquisition can be adapted as per the requirements of the application. The main parameters focused in this paper are mismatch probability [1] and power dissipation with respect to sampling rate.**

I. INTRODUCTION AND BACKGROUND

In the past decade, Wireless Sensor Networks (WSNs) were introduced as a new technological manifestation of wireless networks. The wireless sensors have the ability to sense and monitor the surrounding area, collect and deliver data, usually to a single sink, all to perform solely one specific task [2]. Most of the WSNs deployments are for one specific purpose as reflected in the literature. Many routing, power management, and data dissemination protocols have been designed assuming the WSNs as homogeneous devices and adopts application-dependent routing [3].With the recent advancement in wireless communication technology added by availability of low cost sensors, WSNs have found its applications in various domains like health care, habitat monitoring and many other fields. In the near future, WSNs need to support multiple applications, say safety monitoring and environment data collection within single WSN infrastructure. In [3], this type of WSN is called ubiquitous wireless sensor network (UWSN). This type of architecture not only increases the usefulness of the system but also increases the return-of-investment. Inspired by [4], WSN applications can be classified into three broad categories; 1) *Environment Data Collection Applications*, 2) *Safety Monitoring Applications* and 3) *Mobility Support Applications*. Each class of application has its own characteristics features which lead to different requirements. The research works on designing architecture to support multiple applications on a single sensor network are getting attention as seen in [5] − [7]. However, to our knowledge no work has been attempted

on the issues of information accessing strategies and its impact on information reliability and power consumption.

When information at sources changes over time, there is a possibility that the information we use at particular time is not the same information as at the source. This dynamic nature of the information raises a question of information reliability. Reliable information is very crucial in sensor network application like safety monitoring, where mismatch of information will lead to disasters. The probability of mismatching of information at the end user and at the source is called *mismatch probability* [1]. The *mismatch probability* can be used as a metric which measures the information reliability and is impacted by access method, network delay and the rate at which the information changes. In this paper we assume a sampling process of some dynamic information which is characterized by changes only at discrete points in time. As a simple example, we later use a Poisson process.

For the purpose of our study, we model WSN as shown in fig.1. Although, information gathering from WSNs can be of different ways as per the network topology, we consider direct transmission from a node to the application user/client via a network environment. So, in our analysis, we consider that a single node acts as an information source. It is assumed that different types of sensors are used for different applications. When a single WSN system needs to support different applications with different requirements, the challenges that would face is how to satisfy each individual application without much compromising the overall system performance. In this paper, we try to address the following questions:

1) Considering different applications support WSN, how can we ensure required information reliability?
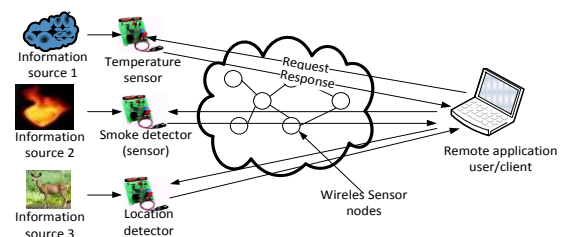2) What is the tradeoff between the need for information reliability and the energy consumption?

Figure 1. An abstract model of WSN considered in the study

II.   RELATED WORKS

Since information quality and energy consumption are the most important performance parameters for sensor network, number of works can be found in the literature. We briefly review few of the works which are mainly focused on improving information quality and low energy consumption with respect to sampling rate.

In [8], a reward and punishing based cooperative adaptive sampling is proposed. This method considers cooperation among nodes to find a balance between energy consumption and the information quality. It uses clustered based sensor network system, where a node which detects frequent phenomenal change increases the sampling rate while the others decrease their sampling rates. In this way, the approach is able to keep the overall network data quality high and minimize the energy consumption by reducing the sampling rate of other nodes.

A two-step approach of adapting sampling called backcasting is proposed in [9] aiming at maintaining high information quality with reduced energy consumption. In the first step, called the *preview step*, an initial estimate of the environment is formed by using subset of nodes. This subset of sensor nodes communicate with the fusion center with this estimated information which indicates that some sensor may not be required in order to achieve a required level of accuracy. So the fusion center backcasts information based on the estimate received and selectively activates additional sensor nodes in the next step, called *refinement step*. Here, the term adaptive sampling is used how many sensor nodes are activated simultaneously rather than how fast or slow the information is transmitted. In this approach, adaptive sampling helps in reducing energy consumption by activating fractions of the available nodes.

An adaptive sampling scheme that responds to the characteristics of the streaming data is developed in [10]. Their approach is based on predictions of future values of a data stream based on Kalman filter. It is based on centralized approach where the activities of the nodes are monitored. The bandwidth allocation is done automatically as per the activity of the nodes. The nodes which show an increase in activity is allocated bandwidth which gives shorter time interval (shorter sampling interval) between successive measurements whereas the nodes which do not show an increase in activity are made to have longer time interval (higher sampling interval).

However, most of the previous works were developed assuming application specific sensor networks. When single sensor network has to support more than one applications, the challenges arise as each individual application has its own set of requirements that needs to be given due importance. As we have described in section I, the preference for requirements differ from one application to another. In this paper, we propose an adaptive information access mechanism which can satisfy different applications without much compromising the overall performance of the system.

III.   SYSTEM MODELS

A. Mismatch Probability Model

The information accuracy or reliability is measured in terms of different parameters in different ways. In [11] and [12], the information accuracy is measured in terms of mean square error which calculates the error between the expected value at the receiver and the real value at the source. However, here we use a parameter called mismatch probability inspired from [1]. In the context of our study, we define the mismatch probability as *the probability that information used by the client at time t_3 is not the information which is available at source at time t_3,* (see fig. 2).

We consider the following two strategies:

Reactive: In this access method, application users/clients initiate a request message whenever the particular information is required, and a response with the information value is returned. From [1] we have an expression for the mismatch probability for reactive accees as

$$mmPr_{Rea} = \frac{1}{E(E)} \int_0^\infty \bar{F}_D(t)\bar{F}_E(t)dt \qquad (1)$$

with F_D as the distribution of delay (t_3-t_2) (refer fig. 2) and F_E the event time interval distribution, and the over line indicating the reliability function, $1-F_x$.

With the assumption of delays and event time intervals are all independent and identical exponentially distributed (with rates λ for event and ν for delay), then (1) simplifies to

$$mmPr_{Rea} = \frac{\lambda}{\lambda + \nu} \qquad (1.a)$$

Proactive: In this access method, instead of application users/clients initiating by a request message, the information sources proactively distribute any updates to the potential application users or clients. The method under consideration does this *periodically*. In this paper we reshape the existing mismatch probability model from [1] to a sampling process by reducing the otherwise included network delay into a deterministic zero delay.

Under the assumption of the time interval between updates being sent are exponential distributed with rate τ, mmPr is expressed as, [1]

$$mmPr_{Per} = \int_0^\infty \exp\left(-\int_0^t \tau F_D(s)ds\right) A_E(dt) \quad (2)$$

with A_E as the distribution of backward recurrence times of the event process. For deterministic delays, and in particular delays of t=0, and exponentially distributed event time process, (2) simplifies to

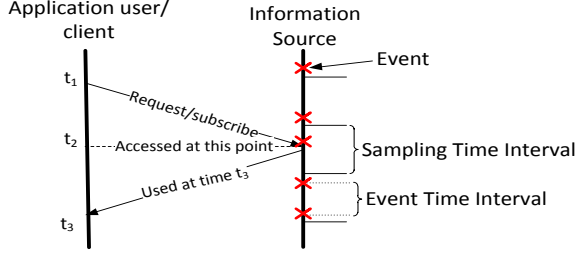$$mmPr_{Per} = \frac{\lambda}{\lambda + \tau} \qquad (2.a)$$

Figure 2. Message Chart Diagram of mismatch probability model

Setting delay to constant zero for (2.a) mimics the situation shown in fig.2 for the sampling process part, and the update rate actually becomes the sampling frequency, i.e. $\tau = f_s$.

The combined mismatch probability can be derived as a weighted average of the two situations: 1) information is already mismatching when being accessed at t_2 which happens with probability $mmPr_{Per}$ or 2) information is correct at t_2 and information changes during time interval t_3-t_2, which happens with probability $mmPr_{Rea}$. The complete mmPr becomes expressible as two separate expressions:

$$mmPr = mmPr_{Rea} + mmPr_{Per}(1 - mmPr_{Rea}) \quad (3)$$

Substituting (1.a) and (2.a) in (3), we get expression of mismatch probability for exponential distributed delays and event process as

$$mmPr = \frac{\lambda(\lambda + \nu + \tau)}{(\lambda + \nu)(\lambda + \tau)} \quad (4)$$

As expected, when ν approaches to infinity (meaning network delay (D) goes to zero) the overall mismatch probability approaches to the mismatch probability of the periodic access (see fig. 3). This shows that the lower bound of mismatch probability is given by the sampling process.

$$mmPr_{per,D=0} = \lim_{\nu \to \infty} \left(\frac{\lambda(\lambda + \nu + \tau)}{(\lambda + \nu)(\lambda + \tau)} \right) = \frac{\lambda}{(\lambda + \tau)} \quad (5)$$

B. Energy Consumption

Energy consumption is considered as an important parameter for WSNs as the sensor devices are mostly powered by battery. Most of the work on WSN in the literature can be seen on how to increase the life time of the network by reducing energy consumption on information transmission. Since, finding the ways to reducing energy consumption is not the scope of this paper, we use simplified version of the relationship between the power dissipation and sampling rate numerically found out in [13] for ADC chip set AD9051, to find out how power dissipation is related to sampling rate.

The simplified version (neglecting second degree term) of power dissipation, $P(\tau)$ equation in [13] can be written as

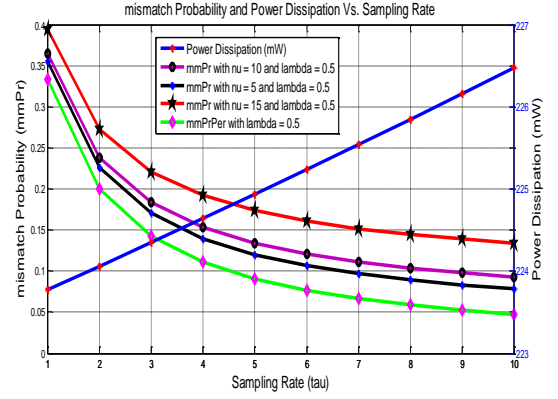$$P(\tau) = 0.2765\tau + 223.4997 \quad (6)$$

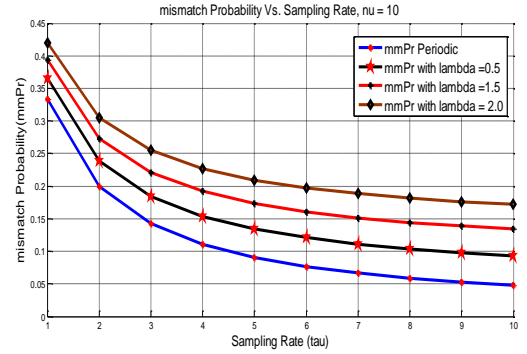Figure 3. Mismatch probability and Power Dissipation Vs. Sampling rate with different values of nu.

Figure 4. Mismatch Probability Vs. Sampling rate with varying lambda

C. Evaluation

As mentioned in section I, our main objective is to study how information can be accessed when different applications with different set of requirements, we analyze how information reliability (with different ν value) and energy consumption are affected by sampling rate. Fig. 3 shows this relationship. It is observed from fig. 3, that the mismatch probability decreases as sampling rate increases whereas power dissipation increases as sampling rate increases.

Fig. 4 shows the relationship between mismatch probability and sampling rate with various event arrival rates (λ). It tells us that as λ increases the mismatch probability also increases. In order to maintain information reliability, the sampling rate needs to increase, but this increases the power consumption. So, it is important to find a tradeoff between information reliability and power consumption which is explored in section IV.

IV. ADAPTION MECHANISM

Referring fig.3, it is observed that the reliability (mmPr) of the information can be maintained at the required level by varying sampling rate. Solving (4), we get an expression for sampling rate (τ) as

$$\tau = \frac{\lambda(1 + \nu)(1 - mmPr)}{mmPr(\lambda + \nu) - \lambda} \quad (7)$$
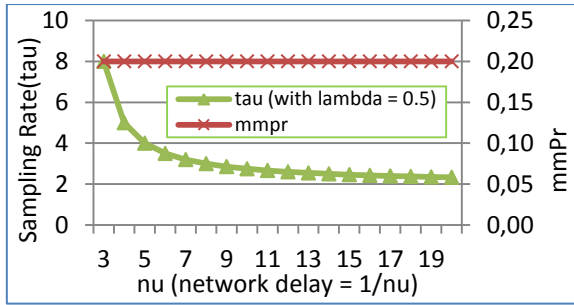
Figure 5. Shows how sampling rate is adapted to maintain mismatch probability of 0.20

Let us assume that an application user or a client wants to access an application, say, safety monitoring application, which requires information reliability of 0.80 (mmPr = 0.20). This requirement can be satisfied by increasing the sampling rate, assuming the information arrival rate is constant as shown in fig. 5. However, this comes at a cost of increase in energy consumption as it can be seen from fig.3. Therefore, we need to find out a tradeoff point between energy consumption and mismatch probability. From (7), one can see that as the denominator term approaches zero, (at mmPr = mmPr$_{Rea}$) one would need to increase sampling frequency to infinite and gain only little reliability (confirmed by the asymptote in fig. 6).

This is thereby the tradeoff point where instead of achieving reliability, it is economical to reduce energy consumption.

Fig. 7 shows how the mmPr behaves with network delay if the sampling rate is kept constant (at some more or less arbitrarily chosen value) illustrating the reliability will vary highly if sampling frequency is not adjusted.
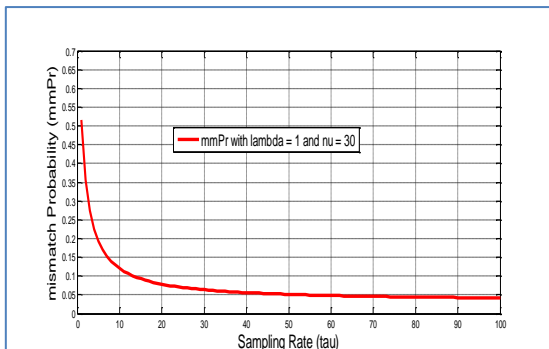

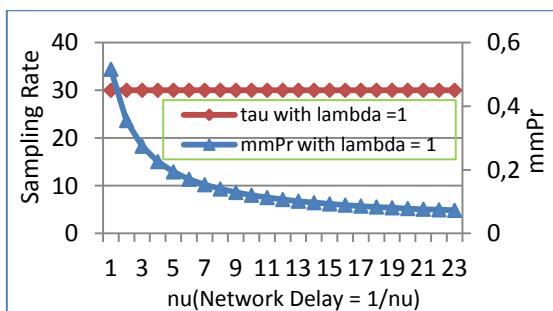Figure 6. Shows that after certain point mmPr remains almost constant no matter how much sampling rate is increased.

Figure 7. Shows the effect of network delay on mmPr with constant sampling rate.

V. CONCLUSION

To increase the usefulness and the return-of-investment of the system, it is very much important that a single sensor network supports multiple applications. In such a system, accessing information from the system would pose some challenges as each application needs to be treated differently as per its own requirements and preferences. In this paper, we have shown how information access can be adapted to application's requirement by adapting sampling rate. As the sampling rate has direct effect on energy consumption, we have also suggested a tradeoff point between reliability and power consumption with respect to sampling rate.

In this study, we considered only few parameters (λ, ν and τ) as causes of information mismatch, but there are other external factors like surrounding noise which also distorts the information signal. Our future work would explore other parameters which affect the mismatch of information.

REFERENCES

[1] M. Bogsted, R.L. Olsen, and H.P. Schwefel, "Probabilistic models for access strategies to dynamic information elements", *Performance Evaluation,* vol. 67, pp. 43-60, 2010.

[2] A. Alomar, and A.H. Akbar, "Carrefour routing for cluster-based wireless sensor networks to support multiple applications in multiple gateway environments", *The 5th International Conference on Mobile Ad-hoc and Sensor Networks (MSN)*, pp. 70-77, 2009

[3] K. Ishibashi, and M. Yano, "A proposal of forwarding method for urgent messages on a ubiquitous wireless sensor networks", *The Proceedings of 6th Asia-Pacific Symposium on Information and Telecommunication Technologies (APSITT)*, pp. 293-298, 2005.

[4] J.L. Hill, "System Architecture for Wireless Sensor Networks", A PhD Thesis, University of California, Berkeley, 2003

[5] M. Akbar, and A.Z. Tanveer, "Multi-Set architecture for multiple-applications running on wireless sensor networks", *24th IEEE International Conference on Advanced Information Networking and Applications Workshops*, pp. 299 – 304, 2010.

[6] J. Steffan, L. Fiege, M, Cilia, and A. Bushmann, "Towards multi-purpose wireless sensor networks", *Proceedings: Systems Communications (ICW'05)*, pp. 336–341, 2005.

[7] M. Akbar, and A.Z. Tanveer, "Running multi-sequence applications in wireless sensor networks", in *Proceeding of 7th ACM International Conference on Advances in Mobile Computing and Multimedia (MoMM2009)*, pp. 365-369, 2009.

[8] A. Masoum, N. Meratnia, Z. Taghikhaki, and Paul J.M. Havinga, "Reward and punishment based cooperative adaptive sampling in wireless sensor networks", *Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP)*, pp. 145-150, 2010.

[9] R. Willett, A. Martin, and R, Nowak, "Backcasting: Adaptive sampling for sensor networks", *in Proceedings of the 3rd International Symposium. Information Processing in Sensor Networks (IPSN)*, pp. 124-133, 2004.

[10] A. Jain, and E.Y. Chang, "Adaptive sampling for sensor networks", *In Proceedings of the 1st. International Conference on Data Management for Sensor Networks*, ACM Press, pp.10-16, 2004.

[11] K. Cai, and G. Wei, "Information accuracy versus jointly sensing nodes in wireless sensor networks", *IEEE Asian Pacific Conference on Circuits and System*, pp. 1050 – 1053, 2008.

[12] J. Karjee, and H.S. Jamadagni, "Data accuracy model for distributed clustering algorithm based on spatial data correlation in wireless sensor networks", Cornel University Library, in press.

[13] M.Xu, H. Li, and X. Gan, "Energy efficient sequential sensing for wideband multi-channel cognitive network", *IEEE International Conference on Communications (ICC)*, pp. 1-5, 2011.