The Effects of FTR-HTTP Control Variables on The Performance of Internet Integrated Sensor Networks

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Abstract: Efforts to integrate sensor networks into internet have been widely pursued. A FTR-HTTP (Finite Time Response Hyper Text Transfer Protocol) has been proposed to integrate the sensor networks with a data collector server through internet. The FTR-HTTP has two control variables, i.e. forced sleep duration (K) and maximum response time ($MaxTr$), in which both affect the performance of the FTR-HTTP. This paper reports some experimental researches that demonstrate the effects of variations of the two control variables on the performance of the FTR-HTTP. The results show that increasing the value of K variable has an effect on the improvements of three performance measures of FTR-HTTP, i.e. average response time, average energy efficiency, and average request timeout. Whereas, increasing the value of K variable can increase the value of average update time, which can be described as a sampling frequency of data transmission to the server. It means that increasing the value of K variable can improve the three performance measures (average response time, average energy efficiency, and average request timeout), but trade off must be made in the expense of average update time. The results of the experiment show that increasing the value of $Max TR$ variable has little positive effect on three performance measures of the FTR-HTTP (average response time, energy efficiency, and average update), but it has little negative effects on the other performance measure of the FTR-HTTP (average request timeout). Finally, a closed-loop control system being able to achieve the optimal performance of the FTR-HTTP, by controlling the value of K and $Max TR$ variables, can be proposed for future works.

Keywords: Sensor network, communication protocol, internet, FTR-HTTP, performance.

1. Introduction

Research on wireless sensor networks has entered into the stage of real application systems that will ultimately leverage the sensor networks. The real applications of sensor networks are employed in the field of health care monitoring systems [1] [2]; environmental monitoring systems [3] - [5]; disaster monitoring systems [5] [6]; intelligent building systems [7]; and smart agriculture. The applied researches on the sensor networks focus on three areas: the development of communications protocols between centralized data collector servers and gateway nodes [8] - [12], the energy efficiency [8] - [13], and the integration of wire sensor networks into internet [14] - [19].

The applied researches on the sensor networks use the internet technology to integrate widely distributed wireless sensor networks with a centralized data collector server. Commonly, the available internet network serves as an ideal solution to connect the sensor network nodes to the server. Additionally, connecting the nodes to the server can be performed quite easily, due to the openness of the internet protocol and the widely supported internet protocol in most network devices as the gateway node. The bandwidth requirement of sensor network applications dynamically depends on the number of gateway nodes and their individual data traffic intensity to the centralized server. The use of the public internet

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infrastructure is quite appropriate to meet the bandwidth requirements, due to the flexibility of subscribed internet bandwidth capacity. Therefore, the internet is a feasible and cost-effective medium for integrating the gateway nodes with the centralized data collector server.

The use of the public internet in integrating the gateway nodes with the centralized data server characteristically has to face the problem of response time uncertainty due to the stochastic nature of the public internet traffic. The problem will be worse with the increasing number of gateway nodes. The uncertainty of the internet traffic inherently results from an unpredictable number and uncontrollable behavior of internet users. The impact of the response time uncertainty is found on the connection between the sensor nodes and the centralized server. The Certain Internet Services Provider (ISP) may claim a guarantee of service, but in practice the claim is rarely met. Therefore, the proposed solution has to consider the uncontrollable behavior of the public internet as an input variable in sensor network applications. The input variable will be used as a control variable for the real application.

In the previous works, the FTR-HTTP (*Finite Time Response Hyper Text Transfer Protocol*) has been proposed to solve the problems [21] – [23]. The protocol works on the application layer of the TCP/IP reference model to manage the data transmission between the centralized data server and the gateway nodes. The gateway nodes are network devices that collect the data from sensors and send them to the centralized data server via the internet. The FTR-HTTP uses a specific mechanism to adjust the periods of data transmission time, a sleep cycle, and forced sleep cycle based on the actual response times, in order to optimize the performance. The performance is measured by the average response time, the average energy efficiency, the average request timeout, and the average time update. The actual response time is used as a control variable of the FTR-HTTP. It becomes a representation of the internet traffic intensity or the actual internet condition. The results of the experiments conducted in the same experimental environment show that the protocol of FTR-HTTP excels other protocols, e.g. the TinyREST protocol and the EEM protocol [23]. In the experiment, the variables of K and $MaxTR$ are chosen as constant variables.

This paper reports the experiment results on the performance effects of K and $MaxTR$ variations. The variables of K and $MaxTR$ are the control variables of the FTR-HTTP performance in regard to the actual public internet traffic intensity or the actual public internet QoS to which the whole sensor system is attached. The results on the FTR-HTTP performance characteristics from the modification of the K and $MaxTR$ in response to the actual public internet traffic intensity become critical information to develop a closed-loop algorithm controlling K and $MaxTR$ values to achieve the optimal performance of FTR-HTTP. The experimental approaches were chosen, due to the complexity of mathematical model relating to the FTR-HTTP performance variables and control variables. Therefore, rather than defining complicated mathematical models, the formulation of dynamic control algorithms is considered to be a more appropriate, realistic, and cost-effective approach.

2. Related Work

A sensor network consists of a spatially distributed autonomous sensor monitoring physical or environmental conditions, such as humidity, temperature, water level, transportation traffic, etc. It records and sends the data simultaneously through either a private or a public network to a certain location of a data collector. The sensor network is comprised of nodes, in which each node is attached to one or several sensors and captures sensor data to be sent to the data collector. The data collector is normally implemented as a data server, to which the data are collected and can be retrieved from. Thus, basically the private or public network connects the nodes to the data collector server. This public network can be a public internet infrastructure. Due to the vast availability of internet infrastructure, the use of internet is preferred to a private network, as a sufficient solution to connect the sensor network nodes to the server.

The main issue in real applications of wireless sensor networks is the energy efficiency. Due to the nature of the sensor networks, the applications are normally operated in areas with limited availability of electrical energy source. Several works on Medium Access Control

(MAC) layer protocol have been proposed to address the energy efficiency issue, such as the protocols of S-MAC [25], P-MAC [26], EX-MAC and TAD-MAC [28]. The purpose of the idea is to reduce the energy consumption by introducing an active-sleep-duty cycle, as shown in Figure 1. During the active periods, the nodes listen and send data to other nodes, and during the sleep periods, the nodes remain idle and they neither sense nor transmit data to the other nodes. The protocols are developed for sensor networks or ad-hoc networks only. However, a problem rises in implementing these protocols on the internet connection with fluctuating traffic intensities. If the nodes do not receive a response until the next duty cycle, during a busy period of the public internet, the sensor network will trigger a HTTP timeout.

Figure 1. Listen-Sleep Mode [25]

Another issue in the research of wireless sensor networks is the integration of wireless sensor networks with external or public networks, e.g. public internet, in regard to the stochastic nature of the public internet infrastructure. The situation causes severe effects on the performance of the sensor network real applications. Several works on application layer of internet protocol, TCP/IP were proposed to handle the problems, such as Tiny-REST [17] and Constrained Application Protocol (CoAP) [18][19]. The proposed protocols have not been able to solve the problems completely, especially in terms of the performance of the protocols concerning to the increase of public internet traffic intensity. The FTR-HTTP shows better performance in overcoming the problem of the increase of the internet traffic intensity [23].

Improving protocols in sensor networks and data collector integration servers using the public internet is still an open area for research, especially in improving the closed-loop control mechanisms to reduce the public internet traffic intensity impact on the real application performance of the sensor networks. This paper is presented, with the experiment results, as an effort to define the best closed-loop control mechanism.

3. Control Variables of The FTR-HTTP

The following figure (figure 2) depicts the generic architecture of sensor network applications which is also known as the Internet Integrated Sensor Networks (IISN) architecture. The architecture was used in the experiments reported in this paper and also used in the previous work on proposing the FTR-HTTP and compared it to the Tiny REST and EEM protocols [23].

Figure 2. Internet Integrated Sensor Network (IISN) Architecture

The work process of the FTR-HTTP can be described in Figure 3, as a simplification of the IISN architecture of Figure 2. The gateway nodes receive the data from sensor nodes by means of active-listen (listening mode) or active-pull (pulling data from sensors). Afterward, the data will be sent to the data collector server using the FTR-HTTP via the internet. If the internet traffic intensity is low or normal, the response time will be shorter than the Max TR. In the condition of low to normal internet traffic intensity, in which the response time is shorter than the Max TR, the data transmissions from the gateway nodes to the data collector server can be carried out periodically without the forced sleep periods. On the other hand, during the high internet traffic intensity period, in which the response time is higher than the Max TR, the gateway nodes periodically enter the forced sleep after a transmit period. The process of the FTR-HTTP is illustrated in Figure 4.

Figure 3. Simplified IISN Architecture

Figure 4. FTR-HTTP

The FTR-HTTP works on two conditions: a condition of non-forced sleep state and a condition of forced sleep state. Those conditions are defined as follows:

$$P_{t+1} = \begin{cases} 1 & \text{if } (RT_t^i < RT_{\max}^i) \\ 0 & \text{if } (RT_t^i \geq RT_{\max}^i) \end{cases} \quad (1)$$

Where:

RT_t^i : response time for event- i at time t (current)

$RT_{\max}^i$: maximum response time (MaxTR) for event- i

P_{t+1} : the next process for each client, and we define 1 as *non-forced-sleep* state, 0 for *force-sleep* state

Figure 5 illustrates the two conditions of non-forced sleep state (1) and forced sleep state (0). If the last response time is shorter than the maximum response time ($RT_{\max}^i$), the gateway nodes are allowed to send data in the next period. However, if the last response time is longer than the maximum response time ($RT_{\max}^i$), the gateway nodes will enter the forced sleep period. The number of the forced sleep periods is set by the value of K variable.

Figure 5. The two conditions of non-forced sleep state (a) and forced sleep state (b)

Figure 6. The Value variation of K variable

Traffic condition of the public internet is a factor influencing the performance of a sensor network real application. This factor cannot be controlled; therefore, the performance control might be carried out by managing controllable variables, e.g. K and MaxTR, in which the values of the variables will be set according to the conditions of the public internet. The traffic condition of the internet can be characterized by an actual value of the response time. If the value of the response time is too high in comparison to the MaxTR, during a busy conditions of the internet traffic, the gateway nodes will enter the forced sleep period. If after one period of forced sleep the response time is still longer than the MaxTR, the number of forced sleep periods can be increased until the response time is less than or equal to the MaxTR. Increasing

the number of forced sleep periods is done by varying the value of K . In the case of a decrease of the actual response time, the value of K variable can also be reduced. The value of $MaxTR$ variable determines the time period to transmit data, thus varying the values of $MaxTR$ set an active period for data transmission. As a result, during the busy period of the internet traffic, the value of $MaxTR$ variable can be decreased to adapt to the internet traffic intensity. To ensure a suitable usage of the two variables controlling the FTR-HTTP performance, an experimental observation should be carried out.

An empirical experiment was performed to investigate the effects of varying the value of K and $MaxTR$ variables on the performance of FTR-HTTP. The value variation of K is illustrated in Figure 6. Increasing the value of K contributes to the number of forced sleep periods that causes a decrease in average response times. The value variation of $MaxTR$ is illustrated in Figure 7. A lower value of $MaxTR$ produces a higher number of sleep periods.

Figure 7. The Value variation of $MaxTR$ variable

4. Experiments and Results

A. Experiment Environments

The experiments were carried out on the public internet infrastructure. The data collector server was connected to the internet, and the gateway nodes were also connected to the server through the internet. The connection on gateway nodes was shaped as a star topology. The topology is illustrated in Figure 8. In the experiment, the gateway nodes were represented by agents behaving like a gateway node in transmitting data. The decision of using the agents was taken due to the insufficient number of gateway nodes for the real experiment scenario. The data transmission behavior of the agents had already been tested to ensure its fulfillment of gateway node requirements.

The experiments were carried out in two categories. The first experiment group was conducted to investigate the effects of varying the value of K variable on the performance of FTR-HTTP, whereas the second experiment group was performed to investigate the effects of varying the value of $MaxTR$ variable on the performance of FTR-HTTP. As stated before, the FTR-HTTP performance was measured in the average response time, the average timeout experience, the average energy efficiency, and the average update time [23]. The process of the

first experiment and its results are reported in the sub-section of 4.2, while the process of the second experiment and its results are reported in the sub-section of 4.3.

Figure 8. The Network topology for experiment

B. Variation Impacts of K Variable on the FTR-HTTP Performance

In the experiments, the values of K variable were varied from 1 to 9. Observations on the effects of K variable on the FTR-HTTP performance were then carried out. Measures of the FTR-HTTP performance was calculated by the average response time, the average timeout experience, the average energy efficiency, and the average update time. Several parameters were determined during the experiments, as can be seen in Table 1. The results of the experiments are presented in Figure 9 until figure 12.

Figure 9. The effects of the value variation of K variable on the average response times

Table 1. Experimental setup parameters to observe the impact of MaxTR

Parameter	Value
Transmission Duty Cycle	Periodically with $\Delta T = 5$ seconds
HTTP Timeout	Same with $\Delta T = 5$ second
Duration of observation	3600 seconds (60 minutes)
Number of nodes	10, 20, 30, 40 & 50
$MaxTR$	2.5 seconds

Figure 9 presents the average response times (vertical axis) as the result of varying the values of K variable (horizontal axis). A higher number of gateway nodes (N) gives more significant impact on the value variation of K variable. The average response time will decrease along with the increase of K value.

A shorter average response time makes the performance of FTR-HTTP better. Therefore it can be concluded that in the conditions of high internet traffic intensity, increasing the value of K can improve the performance of FTR-HTTP.

Figure 10. The effects of the value variations of K variable on the average energy efficiency

Figure 11. The effects of the value variations of K variable on average request timeout

Figure 10 presents the average energy efficiency (vertical axis) as the result of varying the value of Kvariable (horizontal axis). The value variation of Kvariable provides similar impacts on the average energy efficiency for all number of gateway nodes (N). As the value of K increases, the average energy efficiency will decrease. A lower percentage of the average energy efficiency makes the performance of FTR-HTTP better. So, it can be concluded that in all conditions of the internet traffic intensity, increasing the value of K variable can improve the performance of FTR-HTTP.

Figure 11 presents the average request timeout (vertical axis) as the result of varying the value of K (horizontal axis). A higher number of gateway nodes (N) produces a more significant impact to the value variation of K variable. When the value of K increases, the average request timeout will decrease. A shorter average request timeout means that the performance of FTR-HTTP is better. Therefore, it can be concluded that in the conditions of high internet traffic intensity increasing the variable value K can improve the performance of FTR-HTTP.

Figure 12. The effects of the value variations of K variable on the average update time

Figure 12 presents the average update time (vertical axis) as the result of varying the value of K variable (horizontal axis). A higher number of gateway nodes (N) produces more significant impact on the value variation of K variable. As the value of K increases, the average update time will also increase. A shorter average update time means that the data resolution and the performance of FTR-HTTP are better. So, it can be concluded that in the conditions of high internet traffic intensity increasing the value of K variable can decrease the performance of FTR-HTTP.

C. Variation Impacts of Variable MaxTR on the FTR-HTTP Performance

In the experiments, the values of MaxTR variable varied from 2 to 3 second. Observations on the effects of MaxTR variable on the trend of the FTR-HTTP performance were carried out. The FTR-HTTP performance was measured by the average response time, the average timeout experience, the average energy efficiency, and the average update time. Several parameters were determined during the experiments, as can be seen in Table 2. The results of the experiments are shown in Figures 13 through 16.

Table 2. Experimental Setup Parameter to observe the effect of *MaxTR*

Parameter	Value
Transmission Duty Cycle	Periodically with $\Delta T = 5$ seconds
HTTP Timeout	Same with $\Delta T = 5$ second
Duration of observation	3600 seconds (60 minutes)
Number of nodes	50
<i>K</i>	3

Figure 13 shows the average response time (vertical axis) as the result of varying the value of *MaxTR* variable (horizontal axis). The average response time decreases slightly along with the increasing value of *MaxTR* from *MaxTR* = 0 up to *MaxTR* = 2,5 seconds. It can be concluded that increasing the value of *MaxTR* variable can improve the performance of FTR-HTTP slightly from *MaxTR* = 0 to *MaxTR* = 2,5 second.

Figure 13. The effects of the value variations of *MaxTR* variable on the average response time

In the Figure 13, the average response time at *MaxTR* = 0 cannot be determined because when *MaxTR* = 0, it means that the system gets into a forced sleep state forever. Therefore the average response time is unknown. Meanwhile, if *MaxTR* = 5 it means that the FTR-HTTP is not applied in the system.

Figure 14 describes the average energy efficiency (vertical axis) as the result of varying the value of *MaxTR* variable (horizontal axis). The average energy efficiency is improved by increasing the value of *MaxTR* variable from *MaxTR* = 0 up to *MaxTR* = 2. It can be concluded that increasing the value of *MaxTR* variable from *MaxTR* = 0 up to *MaxTR* = 2 seconds can improve the performance of FTR-HTTP. On the other hand, it has no impact on the performance of the FTR-HTTP when the value of the *MaxTR* variable is increased from *MaxTR* = 2 seconds to *MaxTR* = 5 seconds.

Figure 15 presents the average request timeout (vertical axis) as the result of varying the value of *MaxTR* variable (horizontal axis). The increasing value of the average request timeout results in a number of average data retransmission, so it influences slightly the average response time. However, the overall average response time is still improved by increasing the *MaxTR* value (see Figure 13). The average request timeout increases with increasing the value of *MaxTR* variable from *MaxTR* = 0 up to *MaxTR* = 2.5 seconds; If *MaxTR* is greater than 2.5 seconds, increasing the value of *MaxTR* variable has no impact on the performance of

the FTR-HTTP. So, it can be concluded that increasing the variable value of MaxTR lowers the performance of FTR-HTTP only from MaxTR = 0 to MaxTR = 2.5 seconds.

Figure 14 . The effects of the value variations of MaxTR variable on average energy efficiency

In Figure 14, when MaxTR = 0, it means that the system enters a forced sleep state forever. So the system is in the totally sleep state and the energy efficiency is 100 %.

Figure 15. The effects of the value variations of MaxTR variable on the average request timeout

In Figure 15, if MaxTR = 0, it means that the system enters a forced sleep state forever. In such condition, there is no request sent to the server. Therefore, the average request timeout is equal to zero.

Figure 16. The effects of the value variations of MaxTRvariable on the average update time

In Figure 16, if MaxTR = 0, it means that the system enters into a forced sleep state forever, so that there is no data transmission to the server. Therefore, the average update time is equal to infinity.

Figure 16 describes the average update time (vertical axis) as the result of varying the value of MaxTRvariable (horizontal axis). The average update time decreases together with the increasing value of MaxTRvariable from MaxTR = 0 to MaxTR = 2 seconds. From MaxTR = 2 seconds to MaxTR = 5 seconds, increasing MaxTR has no impact on the FTR-HTTP performance. Therefore, it can be concluded that increasing the value of variable MaxTR has a significant impact on the performance of FTR-HTTP improvement from MaxTR = 0 up to MaxTR = 2.5 seconds.

D. Discussion

The results of the experiments explained in the sub-section 4.2 show that increasing the value of K variable will significantly improve the performance of FTR HTTP relating to the average response times, the average energy efficiency, and the average request timeout, in the conditions of high internet traffic intensity, but at the same time it lowers the performance of FTR-HTTP in term of the average update time. The average update time represents the quality of data resolutions in the real applications of sensor networks. Based on these experiment results, it can be concluded that there is an opportunity to optimize the overall performance of FTR-HTTP by controlling K variable and by compromising the trade-off between the FTR-HTTP performance measure set (the average response time, the average energy efficiency, and the average request timeout) and the average update time that represents the data resolution. Therefore, a specification on minimum data resolution requirements of the real applications of sensor networks is essential to control the optimal performance of the FTR-HTTP in the real applications of sensor networks.

The experiment results in the sub-section 4.3 show that increasing the value of MaxTRvariable from MaxTR = 0 to MaxTR = 2.5 second improves three performance measures of the FTR-HTTP, i.e. the average response time, the average energy efficiency, and the average update time. Meanwhile another performance measure of FTR-HTTP (average request timeout) decreases by the increasing value of MaxTRvariable from MaxTR = 0 up to MaxTR = 2.5 seconds. The increasing value of the average request timeout results in a number of averagedata retransmission, so it influences slightly the average response time. However, the overall average response time is still improved by the increasing the MaxTR value. Therefore, the MaxTRvariable has little effects on the FTR-HTTP performance in the range of the

variable value of MaxTR from MaxTR = 0 to MaxTR = 2.5 second or MaxTR = $0.5 \Delta T$ (see Table 1 and Table 2 : $\Delta T = 5$ seconds). While in the range of the variable value of MaxTR from MaxTR = 2.5 seconds ($0.5 \Delta T$) to MaxTR = 5 seconds (ΔT), the MaxTR has almost no effect on the all performance measures of the FTR-HTTP.

5. Conclusions and Future Research

The results of the experiment show that the K variable produces significant positive effects on three performance measures (the average response time, the average energy efficiency, and the average request timeout) of the real sensor network applications using the FTR-HTTP, while at the same time the variable K produces negative effects on the average update time. The increasing value of MaxTR variable improves moderately three performance measures of the FTR-HTTP (the average response time, the average energy efficiency, and the average request timeout) and has a negative impact moderately on another performance measure of the FTR-HTTP (the average update time) from MaxTR = 0 to MaxTR = 2.5 seconds. Therefore, the K variable can be used as a main control variable of the FTR-HTTP while MaxTR variable can be leveraged for the support or secondary control variable from MaxTR = 0 to MaxTR = $0.5 \Delta T$. In addition, the variable MaxTR has to be set not greater than $0.5 \Delta T$ (in the range of value MaxTR = 0 to MaxTR = $0.5 \Delta T$).

The minimum requirements of data resolution of the real sensor network applications are very important to determine the optimum value of K and MaxTR for achieving the best trade-off of the IISN performance that employs FTR-HTTP. Therefore, various types of real sensor network applications will have specific optimal performance based on their minimum requirements of data resolution.

Based on the results of the overall experimental research, further works need to be carried out. The works should cover the research on closed-loop control system engineering to optimize the FTR-HTTP performance by controlling the values of K and MaxTR variables. The closed-loop control system uses the parameters from the public internet conditions and from the requirements of minimum data resolution of the real sensor network applications.

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