Smart Mobile Poultry Farming Systems in Tmote Sky WSNs
Chakchai So–In¹, Sarayut Poolsanguan¹, Chartchai Poonriboon¹, Kanokmon Rujirakul¹, Yupin Phasuk² and Theerachai Haitook²
¹Applied Network Technology (ANT) Laboratory
²Department of Computer Science, Faculty of Science, Khon Kaen University, Muang, Khon Kaen, Thailand, 40002
chakso@kku.ac.th, {sarayut.p, chartchai.p, kanokmon.r} @kkumail.ac.th
yuplua@kku.ac.th and theeha@kku.ac.th

Abstract
Advances in technology have a great impact on human society not only in education and entertainment, but even medical and agriculture sectors. Smart farming amalgamates this in order to enhance productivity and cut the operation cost. Thus, in this paper, we propose a novel smart system based on poultry farming over EVAP systems by utilizing mobile and wireless sensor networks with a well–known sensor mote, Tmote Sky, towards a WCF web service interaction. This system assists mobile users/ administrators to observe, and especially control an environmental behavior including an additional alert feature when there is a sudden environmental change with configured thresholds. The paper describes instruments and components of the key design of the system. For performance evaluation, we also practically investigated transmitted power consumption characteristics of sensor nodes using CTP and Dissemination multi–hop routing protocols.

Keywords: Ad–hoc routing; Evaporative Cooling Greenhouse; Collection Tree Protocol; CTP; Dissemination; EVAP; Smart Farming; Mobile Poultry Controlling and Monitoring; multi–hop routing; Windows Communication Foundation; WCF; Wireless Sensor Networks; WSNs

1. Introduction
Recently, the concept of smart farming has influenced into several sectors in both agriculture and poultry with the purpose of improving productivity and operational cost–cutting as well as the environmental condition concern. The smart process involves many stages, e.g., management, feeding/planting, quality assurance, environment control, and performance and reliability [1].

Evaporative cooling systems (EVAPs) is one of the smart indoor–green house equipment systems, especially used in poultry sectors, i.e., chicken and cow farms [2]. The water–cooling fan–pad and air–controller are the main functions in EVAP used to adjust the air volume flow for temperature and humidity controlled environment with light control depending on breeding requirements.

In general, aside from air and light mechanical controllers as well as feeding and cleaning processes, wired–environmental sensors are required to observe the farming condition, and then report back to the administrators in order to manually adjust the environmental control logic accordingly.

Thus, to embed the concept of smart farming to enhance the productivity of EVAP, several aspects can be investigated; however, our focus is the management and communication on the use and interaction among sensors, administrators, and controllers, all of which are the key issues aiding the mobility and manageability of the overall system.

For decades, the advance of wireless sensor networks (WSNs) technology has a great impact on the human society observed by the growth rate in use due to several distinctive features, i.e., a very small size node with full capabilities – sensing, processing, and transmitting – similar to a tiny computer equipped with customized operating systems, e.g., TinyOS and Contiki [3]. This tiny sensor node or mote is wirelessly placed in distributing leading to the decrease of system failure probability.

Presently, there are a number of sensor motes either fully–equipped packages, such as Tmote Sky, Mica, EYEs, and Xbow, or manually customized user–made with specific modules, i.e., CPU (MSP430, ATmega, and StrongARM) [4]; however, the first two built–in TinyOS are in general uses for both industry and research at a reasonable price.
With a variety of WSNs functions, there are a large number of applications of which the main function is basically for monitoring/sensing purpose in several sectors, e.g., in environment, civil engineering (structural monitoring), military, traffic control, health care and surgery, and especially agriculture [5–6].

With those facilities, however, WSNs come with a particular trade-offs, especially a small battery-operated power source and ad-hoc networking infrastructure by nature. Therefore, a great number of researches have been conducted, practically used in the real world [7–8].

Aside from WSNs, especially limited by a hop-to-hop transmission range, the advance of mobile networking technology has also come to the rising stage. A number of mobile (smart) phones have drastically increased in parallel with the decrease of cost, but greater functionalities [9]. The existence of mobile technology results in user-friendly capability and ubiquitous systems with the improvement of wireless transmission speed and wide range coverage.

Recently, the smart phone offers a variety of tuned-up operating systems, properly used for a mobile device with unique characteristics, e.g., Android OS, Windows Phone (WP), iPhone IOS, Blackberry (RIM), and Bada (Samsung). All of these provide enriched features together with plenty of easy-to-develop tools, system applications, and marketing strategies.

Note that although using Web architecture may be convenient and independent in terms of accessibility, many customized features towards mobile applications are fruitful, such as user-friendly interface for portable screen size, SMS or notification services, and GPS functions.

As a result, in this research, we explore the possibility to utilize a mobile phone architecture integrating with web service interaction to support long-range monitoring and controlling systems including alert notification and GPS global-positioning of sensor node perimeter. In addition, WSNs are investigated in practical use over Tmote Sky [www.memsic.com] in both environmental sensing and data fusion including a wireless mechanical control embedded an external logic board. Then, we evaluated the overall system performance, especially the energy consumption in field test.

The rest of this research is organized as follows. In Section 2, we briefly survey recent research/proposals regarding various techniques as monitoring and controlling schemes including sensor transmission techniques over WSNs. Then, in Section 3, the overview of our architecture will be described in details. After that we discussed the practical performance concerning the energy consumption in Section 4. Finally, the conclusions and future work are drawn in Section 5.

2. Related Work

There are a number of researches and applications in various areas of sensors applying WSNs and mobile networks for the purpose of monitoring and acquiring environmental data and location information, as previously mentioned in brief; however, in this section our focus is on the recent applications, especially in an agriculture sector.

In 2010, F. Dong and N. Zhang [10] proposed an online monitoring system to be used in a poultry farm based on ZigBee in a customized CC2430 controller integrated with different sensors, temperature (TGS4161) and humidity (SHT75). Similarly, with a customized node or sensor mote using HSM–20G and LM 35, in 2011, S. Kalpana et al. [11] investigated a
feasibility to utilize wireless sensor ZigBee networks to monitor air temperature, humidity, and light intensity in a crop field from remote places via web architecture.

Moreover, M. Mancuso and F. Bustaffa [12] proposed the architecture to collect environmental information for crop planting, especially tomato greenhouse farms. They applied Sensicast RTD204 node including SHT71 and RTD204 for air temperature and humidity; and in particular, soil temperature and CO₂ sensors were investigated using a 4 wire PT100 platinum waterproof. Here, the monitoring module is based on web architecture in XML formats. Likewise, T. Ahonen et al. [13] chose Sensinode’s Micro 2420 U100 equipped with SHT75, TSL262R and TGS4161 for four climate variable detection (temperature, humidity, luminous, CO₂) of greenhouse farm in Western Finland.

For all proposals discussed above, they focus on the customized sensor node integrated with external sensors, and so the performance is unlikely easy to evaluate. In addition, they do not discuss the practicality to integrate the controlling logic as well as mobile monitoring usage. Consider the integration of WSNs and GPS. K. Mayer et al. [14] applied Mica2 embedded with GPS (for global position tracking) and external sensors by attaching those into steer to monitor its health condition. Standard web architecture was applied for Internet monitoring. Similarly, I. Andonovic et al. [15] investigated cattle health monitoring systems using different sensor motes, i.e., Mica2 and MicaZ including the hardware and software design discussions.

Moreover, M. Murad et al. [16] proposed Poultry Farm Monitoring System (PFMS) at N–W.F.P Agricultural University based on WSNs using TelosB or its derivative, Tmote Sky, motes integrated with commercial sensors capable of measuring temperature and humidity. Similarly, Y. Wan et al. [17] studied on farm automation integration systems using field servers for country–chicken poultry farm in Taiwan. This study also discussed the effect of other environment sensors, i.e., raining and infrared.

Applying external sensors via WSNs was also investigated by H. Okada et al. [18], i.e., thermometer and accelerometer sensors for a chicken farm, and then was evaluated availability of a method for detecting chicken infected with the highly pathogenic avian influenza (HPAI) viruses using data at early stage.

Note that most of the proposals discussed above applied industrial integrated sensor motes, and only the monitoring usage via web–based architecture was considered. Additionally, although the researchers discussed on the interaction of mobile architecture, the detailed description was briefly described, and none of the systems do support alert services in critical condition.

Consider mobile monitoring over WSNs. G. Virone et al. [19] proposed the system architecture for smart healthcare over WSNs using Windows Mobile OS PDA. Similarly, C. K. Harnett [20] applied a Java ME based–mobile phone for network telemetry over WSNs.

In addition, T. Shiang–Yen et al. [21] investigated the integration of mobile application to improve information sharing and knowledge dissemination using SMS and MMS among farming community, such as weather forecast, date of important farming activities, and recommendation on the use of pesticides and fertilizers.

In particular, to support an alert system, Y. Chu et al. [22] and S. K. Udgata et al. [23] embedded the alert/notification module in terms of SMS services following the detection of sensing alarm, but again not much detail on implementation aspects was discussed. Furthermore, in 2012, C. So–In et al. [24] utilized SMS services over mobile networks for alert including mobile monitoring systems for environmental behavior changes but still lacking of controlling logic toward WSNs.

In terms of production performance analysis and framework, L. Jiuxi et al. [25] examined on production performance parameters, i.e., food intake, excretion, water intake, egg weight, laying time, for poultry using monitoring devices. C. Chen et al. [26] also investigated the framework of culture environmental early–warning systems and embedded devices including online management though Internet or GPRS networks of farming homes.

Note that from various techniques discussed above, there are advantages, but some useful techniques aren’t considered, probably due to the technology inadequacy. As a result, we have proposed a new system to make use of distinctive features of mobile platform for monitoring and controlling the environmental behavior toward a well–known industrial used WSNs via Tmote Sky and mobile networks. We have also discussed the alternative design of the system.
3. System Architecture

Figure 1 shows an overall diagram of a smart mobile poultry farming system. There are three main components: mobile monitoring and control device, base station control server, and client node.

3.1. Mobile Monitoring and Control Architecture

This component is the main interaction of administrators and systems to monitor and control environmental behavior of EVAP farm. There are three modules illustrated in Figure 2.

– Environmental Control and Monitoring: with environmental data stored in a server database, this module displays a human-readable information regarding temperature, light and humidity information including node identifier (ID), such as temperature=25º and humidity=19% over Windows Communication Foundation (WCF) web service in XML-based formats.

Here, there are six functions to support WCF data transmission: `GetALL()` and `GetAverage()` to receive raw data towards WCF, and then transform into appropriate formats (nodeID:environmental data); `SetC(int mode, int val)`, `SetL(int mode, int val)` and `SetHU(int mode, int val)` are used to reset the value (val) of temperature, light, and humidity, respectively. Here, there are two modes, manual (01) and auto (10) including inverse-auto (11) modes, described in details later.

– GPS and Map: this module is mainly used to enable a location processing logic to display the actual position of sensor node perimeter over Bing Map. Note that GPS is suitable for out-door, but location service can also be acquired through cellular services, i.e., through 3G networks for in-door.

– Notification Controller: to support low battery consumption and to save transmission cost, in case administrators only need to be aware of critical changes of environment, but not for regular statistic update, the system enables an alert mode via Microsoft Push Notification Service [msdn.microsoft.com] for alert services.

3.2. Base Station Server Architecture or WCF Server

This component is working as the main base station to receive environmental sensor data as well as to transmit the control data back to each node to activate or deactivate a mechanical part.
Due to the limitation of a special hardware for base station, for our architecture, one of the Tmote Sky motes, attached to a traditional PC server, works for that purpose. Figure 3 shows five main modules for this mote excluding additional module connected with the WCF server via serial interface.

- Transmission Control: this module is the main function for data transmission (send/receive), i.e., with AMSend – a packet transmission interface with data payload to specific addresses – and with Receive – this interface works in the opposite direction of AMSend.

  In addition, a de/encapsulation interface – Packet – for sensor data as well as specific header information is included in this module.

- Timer Control: a timing interface to fire the scheduling time to activate the program (millisecond).

- Leds Control: an optional interface to explicitly notify users when a specific event has occurred, such as reading sensor data/transmitting/receiving the packet.

- Routing Control: to support multi-hop routing in bi-directions, there are two main routing protocols used either transmitting environmental data back to the base station or broadcasting the control data update to all sensor nodes to (de)activate the mechanical parts.

  At this point, Collection Tree Protocol (CTP) is chosen as the first criteria due to the nature of tree characteristics to traverse data back to the root node. In opposite, Dissemination protocol is selected due to the broadcast characteristic when all nodes are required to interact with the control logic for EVAP [27].

- Environmental Monitoring: this module mainly functions as a sensing device, especially with built-in environmental sensors – light, temperature, and humidity. Note that with Tmote-based server, this module is deactivated as unification operation for other components (other sensor motes).

  In addition, Figure 5 shows flowchart of Tmote-based server either forwarding the data back to the WCF server (via serial interface) if there is CTP-based data or distributing the control data to other sensor nodes if there is a command sent from mobile monitoring and controlling platform.

3.3. Client Architecture

Similar to Tmote-based server, five main modules are built-in as a unified architecture: Transmission Control, Timer Control, Leds Control, Routing Control, and Environmental Monitoring; and, here, the sensing function is activated to measure the environmental behavior.

Four main function calls are used in TinyOS; namely, Msp430InternalVoltageC, HamamatsuS10871TsrC, SensirionSht11C, and HplMsp430GeneralIO to interact with environmental data including Analog to Digital (ADC) controller, respectively.

In addition, there is one extra module – Environmental Control which performs the interfacing with an external controller board for control mechanical parts, i.e., light and fan via ADC channel.

Figure 6 shows an external control logic board interfacing with Tmote Sky node. In general, this board is driven by power from the node via u2(9) and u2(1) connectors (power and ground).
With the constrain of power levels to drive the control signal, the connectors GPIO \( u_2(7) \) and \( u_2(10) \) [28] are mainly used for remote control logic. Here, four main components are integrated: diode, resistor, relay, and transistor logic.
Consider a mechanical control part. We chose Beamish (BY–C7E), a small radio frequency remote control switch, as our main radio controller to control other mechanical parts due to several advantages, i.e., low cost, accessible in the local market, wireless communication [beamish.en.alibaba.com].

Figure 7 shows flowchart of client operation. Note that there are two main modes: manual and auto modes. Given a specific time intervals (Timer event), the node will collect environmental data, and send it back to the base station via CTP. Then, an auto mode criterion is checked if that data is within a specific value, the corresponding mechanical part will be (de)activated.

For example, in case the pre–defined temperature is less than a current temperature observed by sensors, a mechanic fan will be turned off and on otherwise. However, if light intensity is less than a specific value, the light will be turned on and off. Note that an inverse–auto mode will perform the operation in the opposite way, especially used in case of sunset/sunrise to turn on/off the light. For manual mode, administrators can manually turn on or off the mechanical part toward Dissemination protocol over a control channel. Note that with this mode, the auto mode will be turned off automatically.

4. Performance Evaluation

In this section, we performed the evaluation process by dividing into two main cases: first, to justify the feasibility of our smart mobile poultry farming systems, and second, to practically show the performance of power consumption based on CTP and Dissemination multi–hop routing transmission logic via Tmote Sky WSNs.

4.1 Experimental Setup

We evaluated our proposal based on two main scenarios to test the feasibility and the performance as follows:

1) To illustrate the feasibility of the system, after our system design has been completed and implemented, we show whether the system is working properly.
   – The sensing device can measure the environmental behavior, i.e., light, humidity, and temperature, and then can be sent over multi–hop CTP WSNs to a base station and finally at the mobile device. Here, we used HTC WP7 600 MHz 158 MB RAM with Windows Phone 7.8.
   – To support the control logic, the mobile user can also manually turn on/off the mechanical logic to adjust the environmental behavior, i.e., light and air flow controller (fan).
   – The mobile user can automatically set up the automate system to tune–up a proper condition of environmental behavior given a specific threshold, e.g., turning on the mechanic fan when the temperature is below some specific thresholds.
   – The mobile user can interact with GPS and location map to specify sensor node perimeters.
   – The mobile user can configure a proper threshold in order to make the system notify any critical events which are then sent through notification services.

With the limitation of our testbed, the base station PC connected with one of the Tmote Sky is on a standard configuration over Windows 8 operating system (32 bits): CPU Intel(R) Core 2 Quad 2.66 GHz (6 MB L2 Cache), 4048 MB DDR–SDAM, 2.5 TB Disk running over VMware (8.04) Linux XUBuntu 2.0 and WCF–Internet Information Service (IIS) 8.0.

For mobile and wireless networks, we used WLAN 802.11b (3Com Access Point with 10 Mbps signal strength measured from the base station) and Microsoft Push Notification Service API as the mobile communication to connect to the HTC WP 7.8 phone.

In addition, since the input from sensor motes is in raw format, we use the equation from [29] to illustrate temperature, humidity, light intensity in human readable formats, e.g., $-39.60 + 0.01 \times (14 \text{ bits raw data})$ for temperature.

2) To practically show the system performance over Tmote Sky WSNs in terms of power consumption of EVAP poultry farm in bi–directions, we configured three built–in sensors to measure the environmental behavior using a multi–hop routing infrastructure, and then transmit the information back to the base station in five seconds interval. In addition, the base station will transmit the control update to other sensor motes in ten seconds interval. Note that we investigated on three motes: motes with sensing and controlling, motes with sensing only, and mote with sensing and relaying capabilities.
Finally, we drew the battery power left—over (Volts) over time period (5 hours). We used Panasonic Alkaline 6LR61XWA LR6 battery 1.5 Volts × 2. We measured 3 times and plot the average voltage. With Tmote Sky, we measured the voltage from the equation [30]: $V_{\text{batt, left}} = \frac{\text{ADC count}}{4096} \times 3$. 

Figure 8. Practical Systems: GUI Screen (HTC WP7)

Figure 9. Prototype: Mechanic Controller+Control Logic Board+Tmote Sky+WP7 (left) and Poultry EVAP Farm (right)
4.2 Experimental Result

For the first scenario, Figure 8 shows practical results in HTC WP7.8 OS GUI. Here, there are three sensor data sent over WSNs using Tmote Sky and mobile communications using WLAN or 3G networks with notification services.

Figure 8(a) indicates that the sensing data can be sent towards multi-hop Tmote Sky WSNs, and finally at the mobile device. Note that since we used the mean of all sensing data due to the physical implementation requirement of EVAP poultry farm, i.e., the mechanical controllers are all only on a particular location.

To support the control logic, Figure 8(b–d) illustrates that the mobile user can manually turn on/off the mechanical part, i.e., light and fan in order to adjust the environmental behavior of the EVAP poultry farm. In addition, the screen to set up the automatic control in order to manipulate the control logic provided a specific proper set of measurement (bar-chart) is also illustrated, i.e., turning on/off the fan given a sensing temperature.

With the limitation of global positioning in WSNs, Figure 8(e) shows an additional feature using GPS on mobile device to specify the placement of wireless sensor motes in global position, and then plot that position on public Bing Map.

Furthermore, Figure 8(f) shows the effect of threshold criteria, and in this example, the temperature is triggered, and the notification was alerted back to the mobile user.

Consider a real world scenario. Figure 9 (left) shows the actual prototype: HTC WP7.8 OS (mobile monitoring and control systems); Tmote Sky Controller Board (wireless remote control logic); Sensing Device (Tmote Sky); Mechanic Controller (light and fan). Figure 9 (right) also shows the actual testbed over the EVAP farm. Note that the control logic does not fully integrate into commercial EVAP controller yet due to the on-going process of farming.

Consider the second scenario. In our experiment, Figure 10 shows that the reduction rate of the mean voltage with standard deviation less than 0.02. Note that in practice, the measurement of voltage levels results in fluctuation of the level; however, the results show the decreasing trend over time. In this figure, for the sake of plotting space limitation, the period from 9900 to 15000 seconds and 2.75 to 3.00 volts were chosen; however, similar trend was applied. It took around 1800 seconds for voltage to start reduction; and 5000 seconds to be in stable stage in decreasing trend of voltages.

Moreover, all sensor nodes’ battery left–over has decreased over time due to the operational logics. However, the sensor node with only sensing capability consumes the least energy. In other words, the batter left–over over time is higher than others. The sensor node with sensing and controlling capabilities has the highest reduction rate of energy. The node with sensing and relaying (multi-hop transmission) has the reduction rate in between of those two. Note that consider measured units, we only investigated the reduction trend of battery power since the actual measured battery power may include additional functionalities not just transmission logic, and we do not focus on the accuracy of power models.
5. Conclusion

New mobile monitoring and controlling systems for environmental behavior towards wireless sensor networks (WSNs), especially applying into the EVAP poultry farm is investigated in this research. We utilized the mobile phone with WCF web service integration in an easy–to–use system for mobile users to observe and manage the environmental condition toward multi–hop routing WSNs including an alert subsystem via notification services for a particular critical event.

In this research, we chose the use of Tmote Sky motes as a well–known sensor motes for WSNs with TinyOS built–in, and WP7 operating system; however, other similar mote architectures and mobile phone technologies are also applicable, e.g., MicaZ and iMote wireless sensors motes; Contigi and LiteOS operating systems; IPhone, Android, Blackberry, and Bada mobile devices.

Due to time constraints in several hours for practical tests, we do not run multiple tests for power consumption evaluation, and this is for further evaluation. We also practically did the field test to the EVAP poultry farm at the Department of Animal Science, Faculty of Agriculture, Khon Kaen University. However, the farming is still in the ongoing–process, so some mechanical parts are not fully integrated in the actual commercialized farm yet. Thus, some performance evaluation results may be altered, but the proposed system can be still applied since the fundamental structure is much similar.

To optimize the energy consumption, although the sensing logic will be either always–on for event–trigger or periodic transmission modes, other transmission optimization could be also applied, e.g., aggregating sensing information for each transmission which costs higher energy consumption than that of sensing logic [24], and similar techniques, say, sleep mode, are for future investigation.

Finally, to simply apply multi–hop routing protocols built–in TinyOS, instead of CTP and Dissemination, other sophisticated protocols are beyond the scope of this study, and these are for future investigation, such as AODV (Ad hoc On–Demand Distance Vector) and DSDV (Destination Sequenced Distance Vector) [7].

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7. References

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