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Energy Efficient Cyber Physical System Using Intelligent Wireless Sensor Network for Faster Disaster Recovery

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ABSTRACT

Cyber physical systems are one of new trends and research topics in recent years. It finds numerous applications including disaster recovery and management. Such disaster recovery systems need to operate with minimum energy source as well as at faster pace. These two issues are addressed in this paper. The major objective of this research work is to design a disaster sensing wireless node interfaced with Cyber physical System (CPS) incorporating energy efficient wireless actuators for faster recovery of disaster (min-delay) with minimum energy. The simulation results show that the designed CPS has good throughput, minimal end-to-end delay (faster rescue), high bandwidth delay product and minimal energy utilization.

Keywords: Cyber Physical Systems, Energy Efficient, SensorNetworks, Disaster

1. INTRODUCTION

Disaster recovery and management is a demanding research area where vast research is going on to solve various real time issues. The most important factors affecting a disaster recovery is speed of recovery and latency of disaster alert. Now-a-days, Wireless sensor networks (WSN) find several applications such as disaster management, military applications, security and surveillance applications, target tracking, etc. Recently, WSN has attracted the attention of researchers to use wireless sensor actuator network for disaster recovery applications. The physical world parameters are sensed by various sensors interconnected over wireless network. Then the sensed parameters are analysed for further process. Based on the sensed values the corresponding wireless actuator is actuated for control. WSN.

Another growing research field is Cyber physical system (CPS) [1], which is an inter-disciplinary research area integrating the physical system variables with initial conditions. When the initial condition changes the CPS yield different outputs and variables are affecting the physical nature of the system. The CPS can be used to sense and analyse various real world physical parameters, environmental variables relevant to disaster. The disaster occurrence can be sensed by various environmental sensors such as pressure, vibration, temperature , etc through CPS. The dynamic variation in these parameters will be stored in plato images. The image patterns will be compared with the reference or standard patterns. The two different technologies respectively CPS and WSN [2] used for disaster recovery and management are sharing the variables and parameters related to real world environment leading to disaster condition. Apart from these, this paper considers Energy and latency for disaster alert and disaster recovery. The research challenges are how to reduce energy consumption and latency for disaster alert and disaster recovery. Integrating CPS and WSN for disaster recovery minimise the energy requirement and delay for disaster management.

This paper is organized as follows. Section-I describes the need for CPS , importance of disaster recovery and significance of this research work. Section-II reviews the literature in the field of wireless sensor

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networks, CPS and autonomous computing. Section-III states the proposed work followed by its implementation methodology, results and discussion in section –IV and section-V concludes the paper.

2. RELATED WORK

An innovative paradigm can be built around the notion of being “globally virtual, locally physical” which expresses that manipulation of physical world but control and observation is done securely across virtual network [9-12] proposed a CPS architecture called CPeSC3 (cyber physical enhanced secured wireless sensor networks integrated cloud computing for u-life care). This architecture is composed of three main components, namely 1) communication core, 2) computation core, and 3) resource scheduling and management core. They adopted cloud computing technology in the context of healthcare application. But they lack the details of alarm system of sensing data which is addressed in our proposed architecture. CPeSC3 doesn’t highlight on complete reliability of system which is vital for any CPS healthcare application. In [13], authors tried to answer the limitation of CPeSC3 but failed to propose a complete CPS architecture. A promising framework has been proposed in [14] where automated secure framework of community cloud would provide cheaper healthcare service with the end-goal of better health outcomes. But in their architecture, the issue of alerting the physicians in emergency has been left unanswered. An intelligent sensor network based disaster recovery system with CPS and autonomous network was presented in [15]. This paper presents intelligent wireless sensors and actuators for disaster sensing and control through physical interface system.

3. PROPOSED WORK

This research paper proposes an CPS based intelligent control system as shown in Fig 1. In this CPS, there are some reference states defined initially called as normal states. The other states are called as abnormal ones.. The CPS periodically collects the real world information of the physical system through wireless sensors. This new system uses a new method of sensing with CPS which senses status of the physical world environmental parameters using wireless sensors in real time, and then interacts with physical systems through wireless actuators which recover disaster. This research work has following 3 phases.

i. Disaster wireless sensor design.

ii. Interfacing environmental parameters with CPS.

iii. Actuating faster disaster recovery with wireless actuators.

The CPS senses status of the physical world environmental parameters using wireless sensors in real time, and then interacts with physical systems through wireless actuators which initiate disaster recovery functions as shown in Fig 1.

The sensor node design for sensing disaster is shown in Fig. 2. It consists of the following sub units.

i. Sensing Unit

ii. Processing Unit

iii. Cognitive Radio unit (ADC & RF units)

iv. Memory Unit

v. Battery & recharging units

The sensed environmental parameters are interfaced through cyber physical system. The essential parameters are:

i. Vibration

ii. Humidity

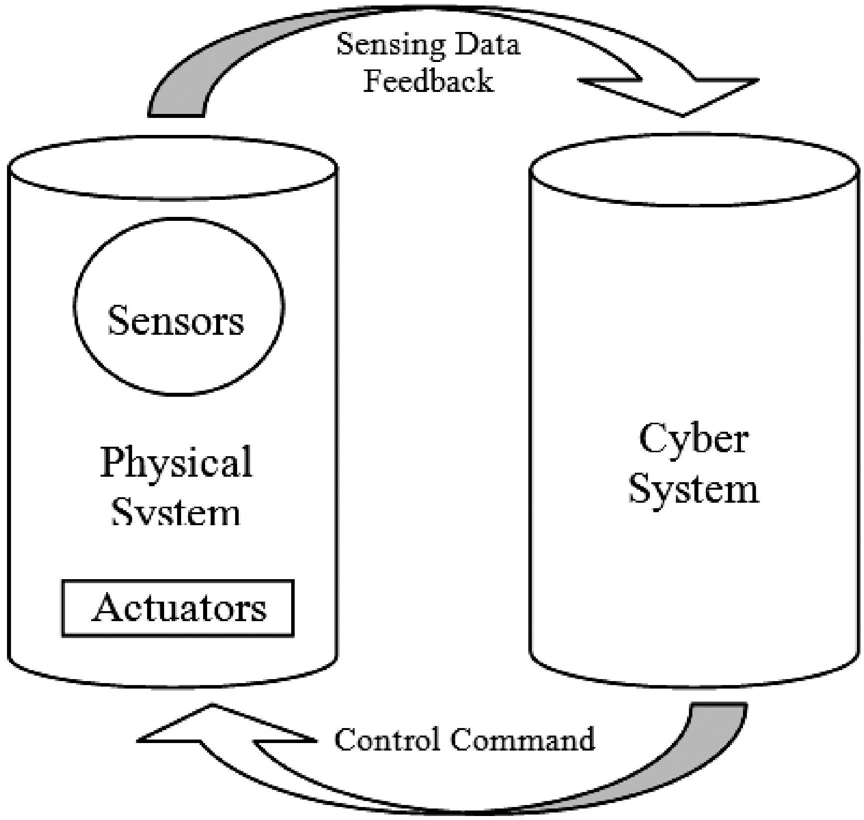

Figure 1: Interaction in Cyber Physical System (CPS)

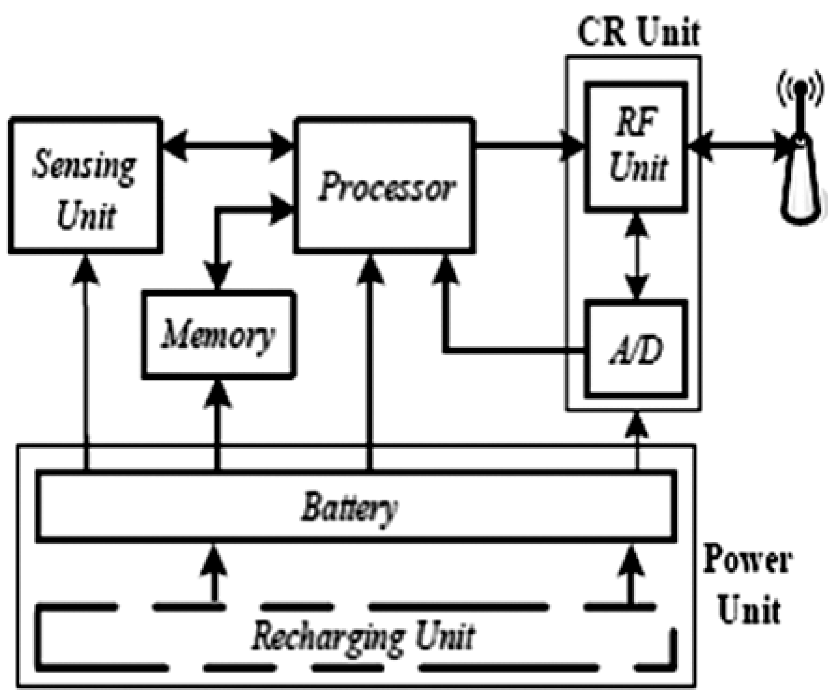

Figure 2: Wireless sensor node for disaster sensing

iii. Pressure

iv. Temperature of Earth

The various stages for automatic disaster recovery system using CPS is shown in Fig 3, which consists of the following sub modules.

i. Physical system for sensing environmental parameters
ii. Plato image generation
iii. Processing / Optimization unit
iv. Physical interface unit to the outside world

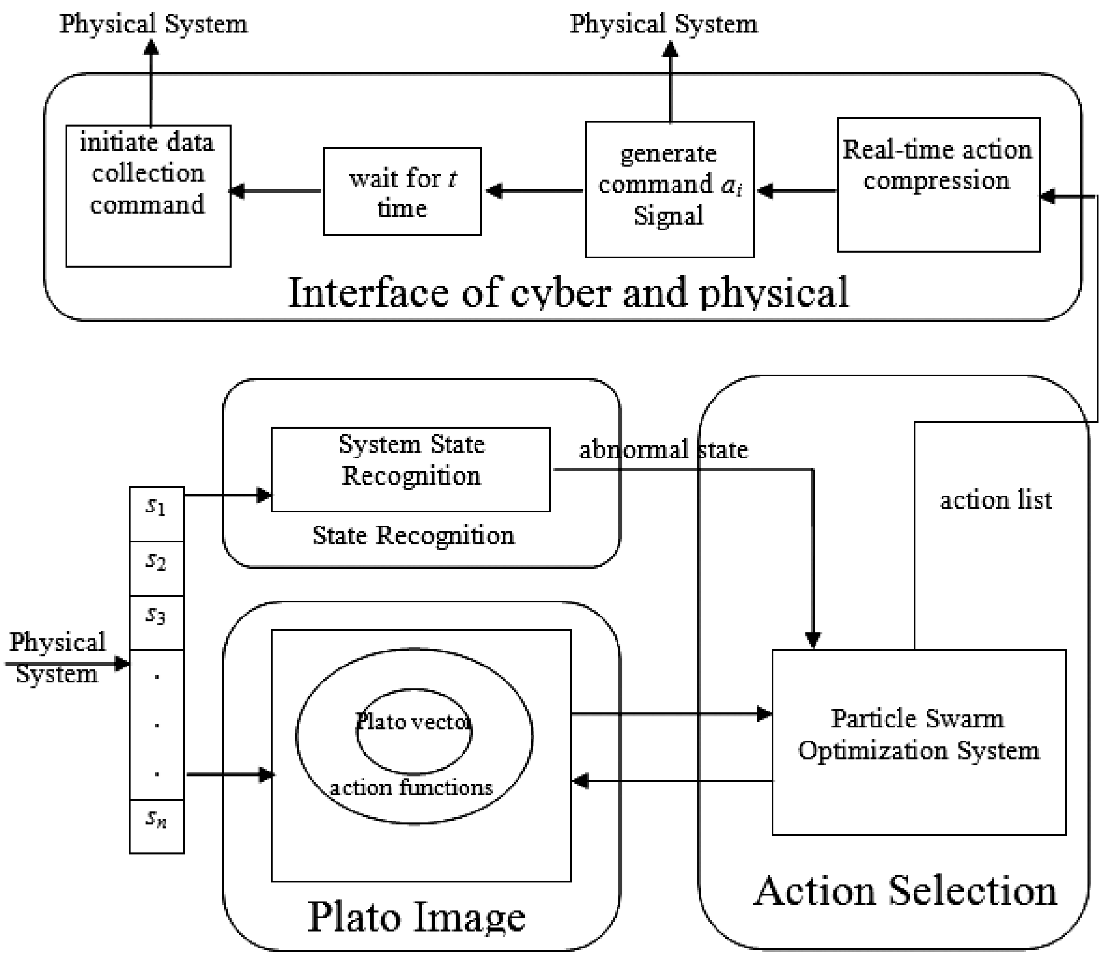

Figure 3: CPS based Automatic Actuator / Control system

4. RESULTS AND DISCUSSIONS

This section describes the simulation method followed for the CPS based wireless sensor network control and simulated results and observations. We have used MATLAB version R2011a to model the hardware

Table 1
Simulation Parameters

Parameters	*Specifications*
No.of nodes	100
Area	1000 × 1000
Channel	Free space propagation model
Data rate	2 Mbps
Packet size	10KB
Buffer size	15 packets
Initial energy / packet	2 joules
Packet drop rate (ave)	0.01

and software associated with the CPS and integration of communication modeling with the help of SIMULINK tool using “in the loop technologies” to interface between the system and cyber world. The experiment for measuring the performance of CPS with WSN for wireless sensor actuators is done with MATLAB-SIMULINK setup with the following parameters listed in Table 1.

The simulation experiment is creating an environment with a cluster of nodes in the area 1000x1000 with free space propagation model. The initial values for the sensor nodes are assumed as normal values. The dynamic changes in the physical status of real world are recorded as plato image. The deviation from the reference valued plato image will be notified as abnormal one.

Table 2
QoS Parameters

QoS Parameters	*Expression*
Bit Error Rate	$F_{min-ber}$ =log 10 (0.5)/ log 10 (P_{be})
Power Transmission efficiency	$F_{min\text{-}Power}$ = P/P_{max}
Spectral utilization efficiency	$F_{max-Spectraleff}$ =1- (M*B_{min}*RS)/ (B*Mmax*Smax)
Throughput	F max –throughput = 1-$\log_2$(M) / log 2 (M_{max})
Detection latency	$F_{min-interference}$={(P+B+TDD)-P_{min}+B_{min}+1{(P_{max}+B_{max}+S_{max})

where, M-modulation index; B- Bandwidth ;
P-power transmitted; Pmax-maximum available power,
TDD- Time division Duplex; Smax – Max symbol rate;

The performance measure of this CPS initiated WSN is analysed through several experimental study, observing various Quality of service (QoS) parameters namely network throughput, latency, network lifetime, energy level, etc as shown in the table 2. The simulation was carried out in the following four levels.

i. Model in the loop simulation (MILS)

ii. Software in the loop simulation (SILS)

iii. Hardware in the loop simulation (HILS)

iv. Model Design Optimization

The above QoS parameters were optimized using multi-objective optimization problem modeling. The final optimal parameters are evaluated using MATLAB Optimization toolbox as shown in Fig. 4.

While measuring the disaster recovery performance, the artificial disasters are imitated randomly by a few number of random nodes in the cluster region. Every time, one node will be active and behave as a target. After leaving this active node, a new node will be assigned as active target node in that region. When

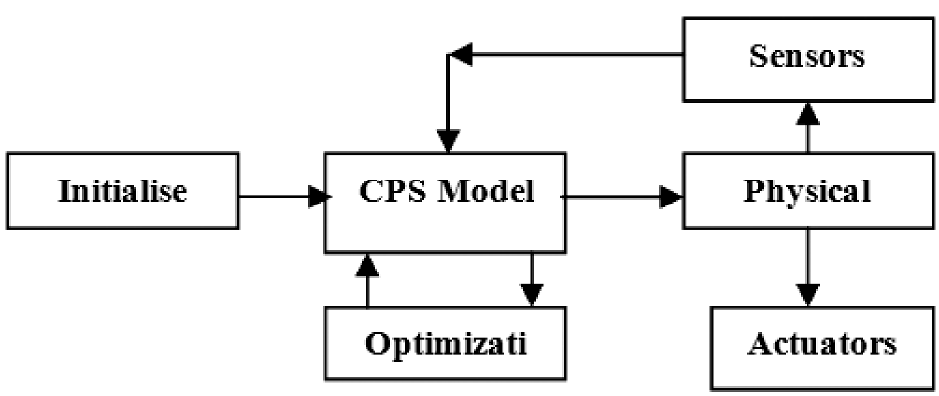

Figure 4: CPS Model and Design Optimization in MATLAB / SIMULINK

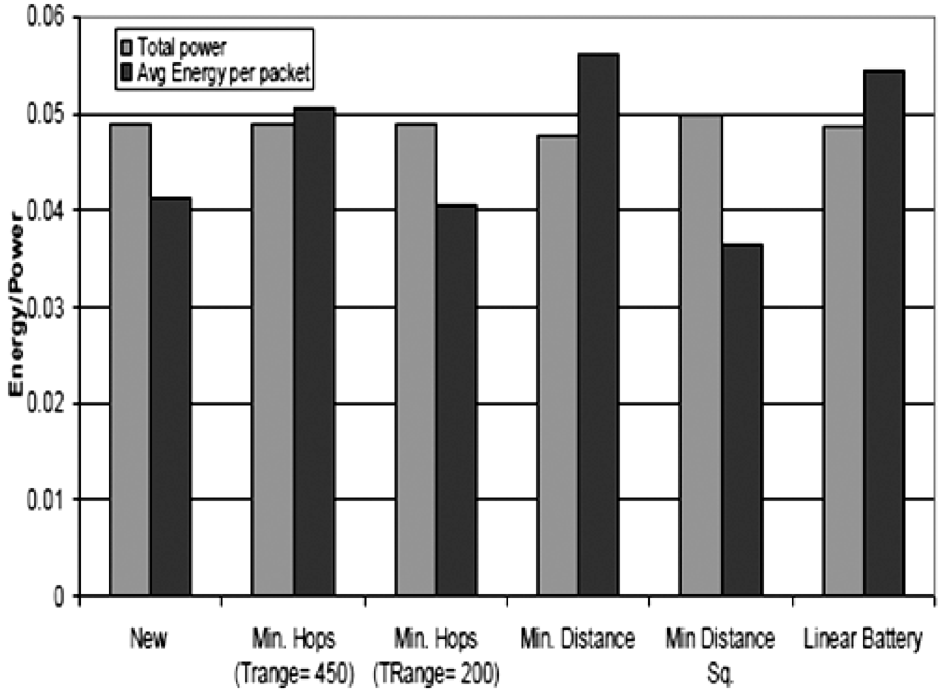

Figure 5: Energy metric for various scenarios

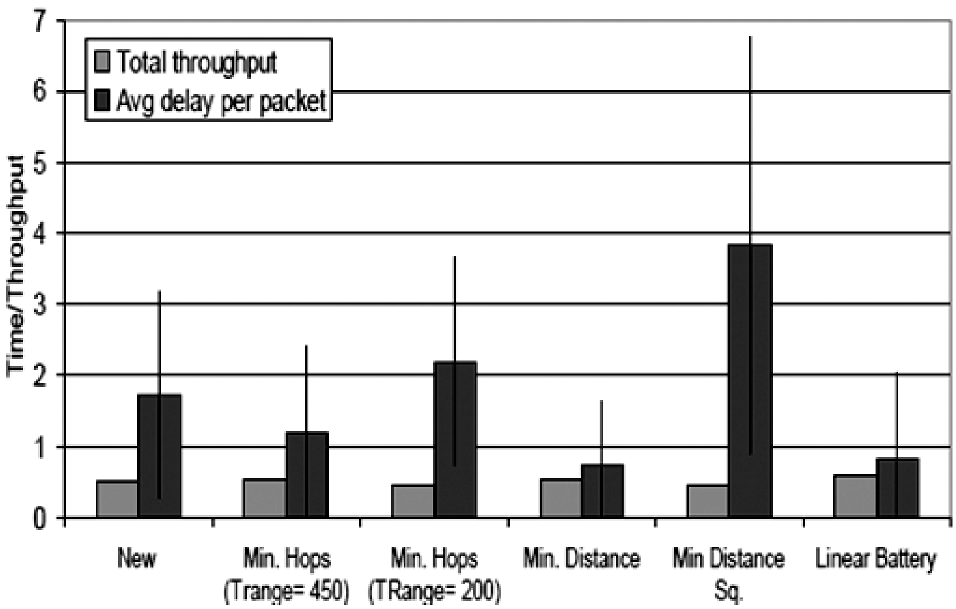

Figure 6: Throughput & End-to-End Delay performance

the traffic load of the nodes increase, the network throughput continuously increases up to the maximum value. This is due to the proactive nature of the intelligent prediction of disaster parameters in the physical world through CPS. The energy consumption under various scenarios of new node, minimum hops, minimum distance, and linear battery is shown in Fig 5. While incressing the buffer size for the particular cluster of nodes, the end-to end delay is increasing to some extent and then remains constant as shown in Fig 6. This is due to stable nature of CPS which responds instantaneously with real world changes.

While the energy consumption of CPS based WSN nodes is decreased as shown in Fig. 5, the measured throughput for the CPS is increased while the delay value decreased as shown in Fig 6. The decreased energy consumption is due to energy optimization of the sensor nodes. The plot shown in Fig 6 compares the throughput and delay values of the CPS shows that the better network performance.

The above graphical analysis show that the CPS network has increased throughput with high data rate while minimized delay. The delay Bandwidth product of the CPS also increased. This ensures that the disaster recovery will be faster with minimal energy. Also due to the energy efficient routing algorithm it uses the lifetime of the CPS nodes increased.

5. CONCLUSION

This paper proposes a new energy efficient method for disaster recovery using Cyber Physical system concept. The existing technologies for disaster recovery are utilizing maximum energy and high latency of detection. This research addressed these two issues by incorporating intelligent wireless sensor with energy efficient wireless actuators for disaster recovery. The CPS based intelligent disaster recovery was modeled using MATLAB R2011a and simulated using SIMULINK tool. The simulation results show that the designed CPS has good throughput, minimal end-to-end delay (faster rescue), high bandwidth delay product and minimal energy utilization.

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