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Modeling and Analysis of Communication Subsystem design Process for Wireless Sensor Networks based on Petri Net

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Abstract: ***Wireless Sensor Networks (WSNs) have numerous applications in the field of engineering. These networks have variety of design constraints and energy is most important one. As energy harvesting is not possible in most of the cases, energy conservation is the only option available to the researchers. Energy efficient communication is the key to energy conservation as most of the energy is spent in transfer of data from one node to another. This article is devoted to development of energy efficient communication system design process model based on Petri Net for Wireless Sensor Networks. This model not only facilitates to examine the dynamicity in design process but also evaluates the design process for any deadlock conditions. Based on this model, radiating element array for communication in sensor networks can be designed and developed and therefore can be used to improve the overall energy efficiency of the network.***

Keywords: ***Petri Net, WSN, Process Model, Radiating element Array.***

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are prominently used in industrial and scientific societies. These have applications in every field of life like transportation and logistics, precision agriculture and animal tracking, environmental monitoring, urban terrain tracking and structure monitoring, entertainment, surveillance and security, health monitoring, smart grid and energy control systems, industrial applications and so on [1]–[3].

WSNs consists of multifunctional and autonomous sensor nodes. These nodes are scattered in a zone to capture an event or to measure a physical magnitude of the event. After capturing the information from the surroundings, these nodes send it to base transmitting station which is away from the coverage area [4],[5].

In wireless sensor networks [6] each node has the ability to sense, analyze and communicate the information or data from the surroundings. A big number of sensor nodes are required for gathering information about a large area or surrounding in a network. Sensor nodes coordinate among themselves for gathering and processing useful data and communicate the same to a shared base station base station [7]. Although energy is required in each and every process occurring inside a sensor node but most of the energy is consumed in the process of communication from one node to another node or between one node and base station.

Sensor nodes are generally powered by small consumable batteries which cannot be replaced. These nodes should consume small amount of energy such that the life period of WSN. So, the main concern in designing the network is to increase the lifetime of network which can be achieved by conserving energy [8]. Simulators are used to scan the properties and performance examination of network protocol designed for WSN. However, a protocol provides good results on simulators but may fail completely in real world. A fault in protocol can reduce lifetime of WSN and can increase packet loss [9]. Therefore, some formal modelling techniques must be used for analyzing the system.

Petri Nets (1962) are used to design, analyze and evaluate performance of WSN. Petri Net express and represent formalism for modeling discrete event system where events occur according to various stochastic process [10]. Not only the network but even the node in a network or processor used in nodes can be easily modeled efficiently by using PN and it outperforms the simulation based and mathematical models [11]. A wireless sensor network model for evaluation of performance, especially energy consumption with packet loss constraint is widely used. These metrics are used to minimize data packet loss and maximize network lifetime before implementing routing protocols in real world [12].

Therefore, in wireless sensor networks, energy consumption in communication is an important factor in deciding the lifetime of the network. The part which mainly decides communication efficiency is the radiating element attached to the node. An energy efficient communication system should be used for an energy efficient wireless sensor network. Parameters selection is one of the important tasks for communication module in a particular sensor node [13].

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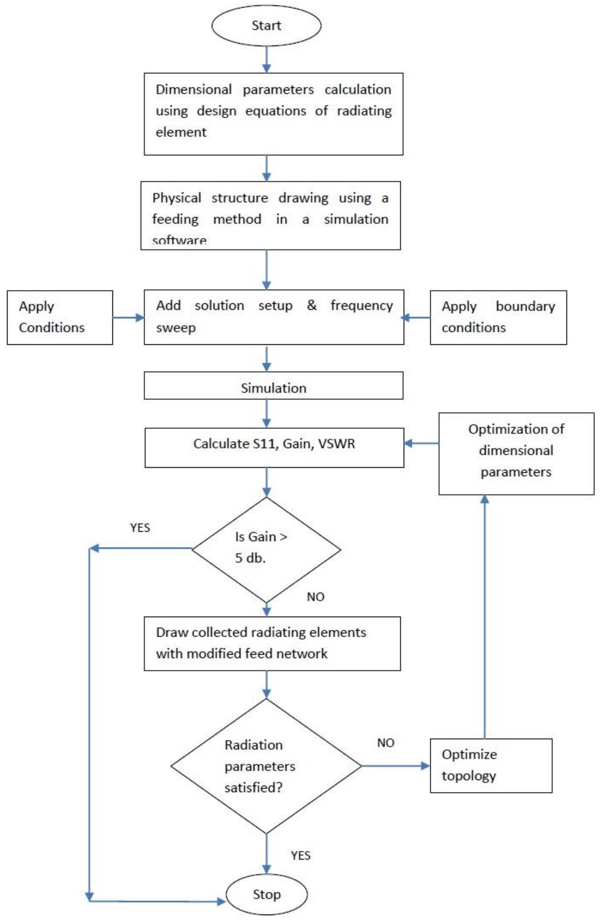

Fig. 1. Flowchart for Designing Model

Petri Net tools are available for the users to view the overall system graphically and edit it with editor. These tools are required to study the properties of system models and simulation for performance evaluation of the developed models. Different tools have different capabilities and limitations of each of them.PN Toolbox has been developed and used with MATLAB for drawing, editing, simulating and analyzing Petri Nets [14].

The standard approach to structural properties of Petri nets (such as boundedness, conservativeness, repetitiveness and consistency) is based on the compatibility of different systems of linear inequalities [15].The users are not required to develop codes and therefore can focus on modelling, simulation, analysis and design of their system models.

In this paper, we have presented a multi-node communication system in which the process (see Fig. 1) modelling of communication subsystem designing has been done by Petri Net and the model is analyzed and simulated in MATLAB.

The radiating elements thus designed when integrated with the nodes of the WSN can improve their energy efficiency and other network parameters.

II. DEVELOPMENT OF COMMUNICATION SUBSYSTEM DESIGN MODEL USING PETRI NETS

A Petri Net (PN) is a weighted and directed bipartite multigraph and is used for defining and analyzing the behavior of a system. Being a graphical tool, it has the capabilities of a flowchart, block diagram while being a mathematical tool enables us to derive state equations as required. Petri nets were first introduced for representation of chemical equations in 1962 by Carl Adam Petri in his dissertation [11]. The description and properties have been studied earlier with the help of some discrete system design applications [16].

The execution of Petri nets cannot be determined until we have a predefined execution policy. Multiple transitions can be enabled at same point of time and any one out of them can fire because tokens can be present at more than one place at the same time so, Petri Nets are suitable for modeling concurrent, synchronous, distributed, parallel and even nondeterministic systems [17]-[18].

The developed designing model based on Petri Nets is shown in Fig. 3. The tokens are initially placed in p1, p4, p5, p8 and p10. The tokens at places p4 and p5 denotes necessary conditions. The token at position p8 denotes that the gain is sufficient while the token at position p10 shows that the parameters are satisfied.

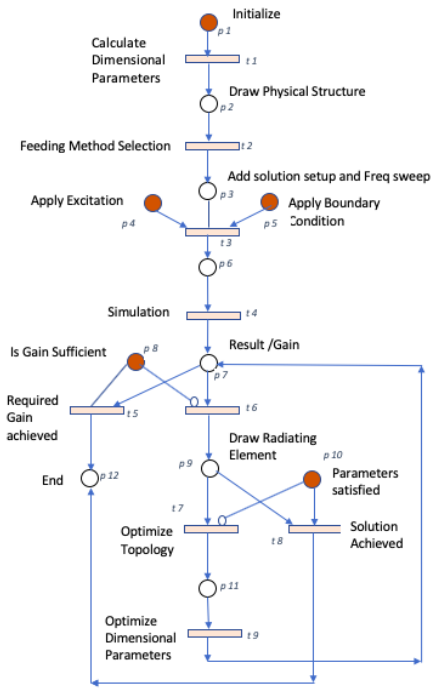

Fig. 2 Petri Net model of design model in Fig. 1

Description, arrangement of position and transition of developed model are presented in Table 1 and II respectively.

Table- I: Description of Positions of Design Model

P1	Initial position of model
P2	Designing dimensional structure
P3	Add solution setup and frequency sweep as per the requirement
P4	The token at this place indicates that the excitation is applied.
P5	The token present at this place indicates that boundary conditions are applied.
P6	This position indicates the process of finding design parameters.
P7	Results as parameters are calculated
P8	A buffer position intended to check whether parameters achieved are sufficient or not.
P9	Draw radiating element
P10	A buffer position intended to check whether parameters are satisfied or not.
P11	Position for indication of necessity to change the physical parameter.
P12	Model completion position

Table -II: Description of Transitions of Design Model

T1	Dimensional parameters calculation using design equations
T2	Physical structure evaluation
T3	Solution setup and frequency sweep
T4	Electrodynamic analysis using simulation
T5	Required parameters achieved
T6	Parametric analysis
T7	Optimized topology
T8	Required solution achieved
T9	Optimized dimensional parameters

III. PROPERTY ANALYSIS OF DESIGN PROCESS MODEL

The PN Model for communication subsystem designing can be constructed in PN Toolbox in MATLAB as shown below in Fig. 4 [19]-[20].

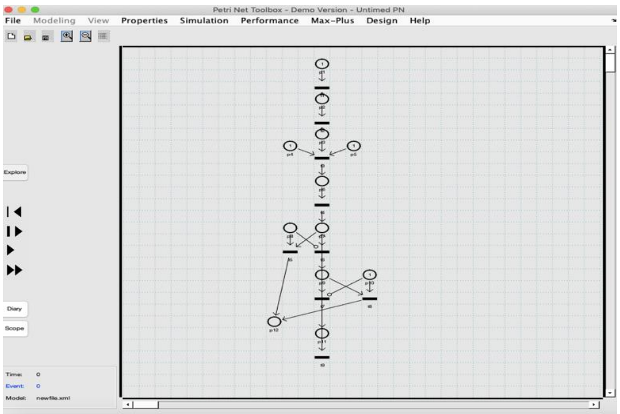

Fig. 3 PN Model of design process in MATLAB

The incidence matrix for further mathematical analyses can be calculated as shown below in Fig. 5.

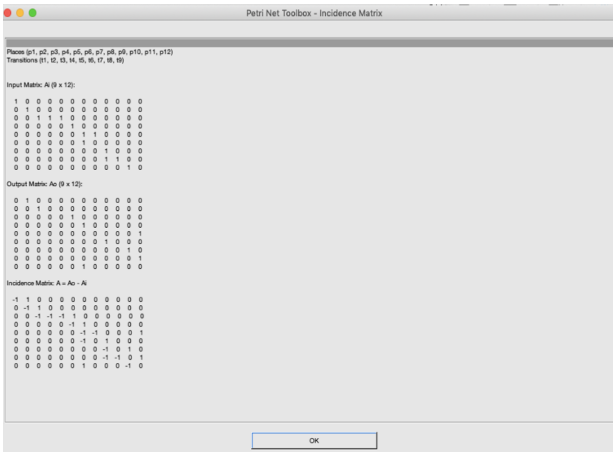

Fig. 2. Incidence matrix for array model

The model is found to be live that means each transition is fired at least once and therefore, each state is significant in this model, as shown in Fig. 6.

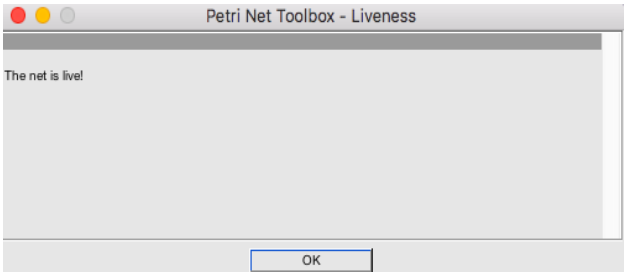

Fig. 3. Liveness of design model shown in Fig.3

As can be seen below in Fig. 7 and 8 the model is not only conservative but also consistent i.e. no tokens are consumed during the process.

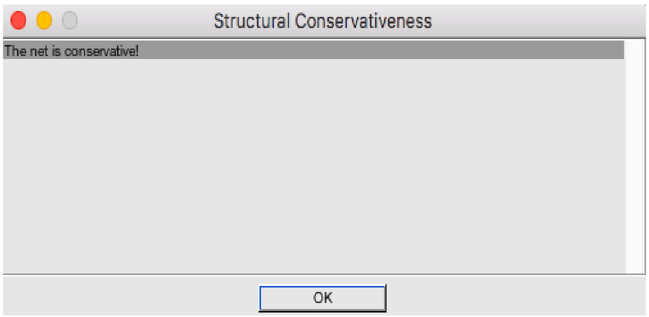

Fig. 7. Conservativeness of design model shown in Fig. 3

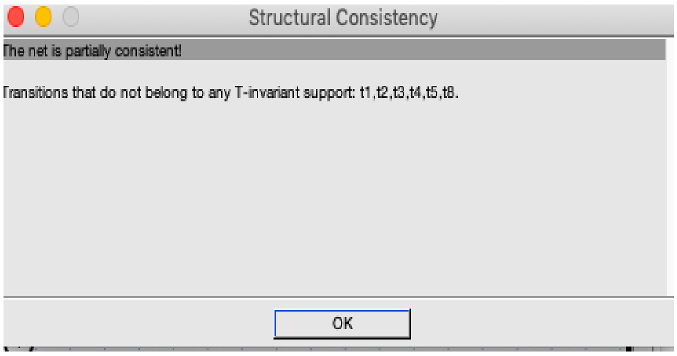

Fig. 8. Consistency of design model shown in Fig. 3

The cover-ability tree explaining the movement from one state to another can be made in graphic mode using PN Toolbox as shown in Fig. 9.

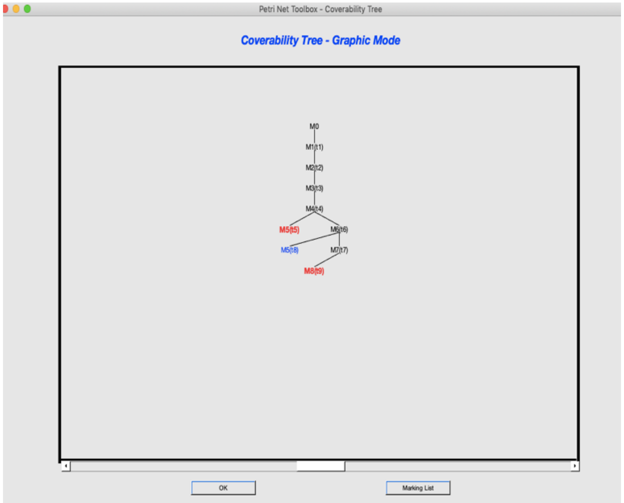

Fig.9. Coverability Tree for design model shown in Fig. 3

It demonstrates that every state in this model is finite and feasible and represents non-presence of any deadlock or undefined situations.

Table- I: Summary of Property Analysis of Models

Properties	PN Model	Imperative Points
Incidence Matrix	Constructed	Used for mathematical analysis
Coverability Tree	Drawn	The model is deadlock free
Liveness	Yes	All transitions fire atleast once
Consistency	Yes	No tokens are consumed
Conservativeness	Yes	No tokens are consumed

IV. CONCLUSION

The Petri net has applications in almost all areas of engineering and science especially in process modelling and communication models. The Petri net theory is used very frequently in technical scenarios because of its efficacy in modelling and analysis of various systems. This theory has been used to analyze design process modelling for energy efficient communication subsystem in Wireless Sensor Networks. This model not only facilitates analysis of design process dynamics but also evaluates the design process for any deadlock conditions. The developed model is analyzed and simulated using PN Toolbox in MATLAB and property analysis of this models demonstrates finite and feasibility of each state and absence of any deadlock or uncertain conditions. Based on this model, we can design and develop our radiating elements and the overall energy efficiency of the network can be improved. The developed model has imperative applications in energy efficient wireless communication networks.

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