Energy Aware Power Save Mode Management in Wireless Mesh Networks

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Introduction

Related works

Proposed Model

Mathematical Model

State diagram

Algorithm

Analysis of proposed algorithm

Conclusion and Future work

Introduction

- In wireless mesh networks, battery plays a major role in deciding the efficiency of routing protocols.
- battery energy draining rate is higher during transmission state
- IEEE 802.11s standard introduced a mechanism called Power Save Mode (PSM) in which mesh station (STA) acts in three different modes such as active, light sleep and deep sleep mode.
- This mechanism reduces energy consumption of STA and increases network life time.

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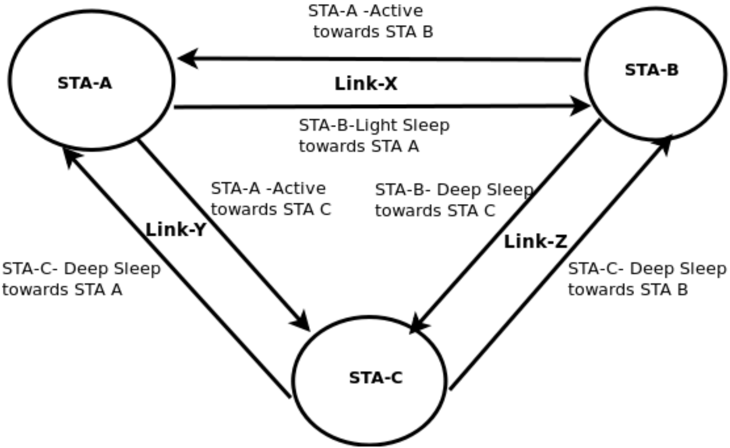

Figure: An example of mesh power mode usage

Outline

Related Works

- The importance of Announcement Traffic Indication Message (ATIM) field scheduling, data frame exchange between STAs and minimizing energy in link specific power save modes in IEEE 802.11 PSM is addressed in existing power saving schemes.
- Most of the reported works have focused on improving energy efficiency by keeping the node in sleep mode.
- It has been found that no work has been carried out till date to trigger PSM mode while considering battery energy of node and improving QoS of a network.
- In this paper we propose a method which triggers power save mode considering remaining energy of a STA and its involvement in transmission mode.

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Proposed Model

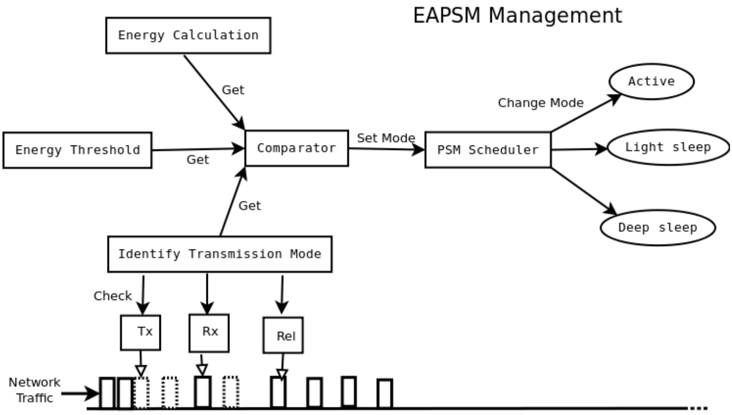


Figure: Proposed model for EAPSM management

The proposed model comprises of three modules namely,

- **Energy consumption calculator:** Calculates the remaining energy of a node at a regular interval of time.
- **Transmission mode identifier:** Identifies the nodes involvement in transmission such as receiving or transmitting or relaying packets.
- **PSM scheduler:** Compares the remaining energy of a node with the energy threshold required by the node to be involved in transmission.

Outline

General equation to calculate energy consumption of node

- Considering data rate and packet size Energy required to transmit a packet is given by

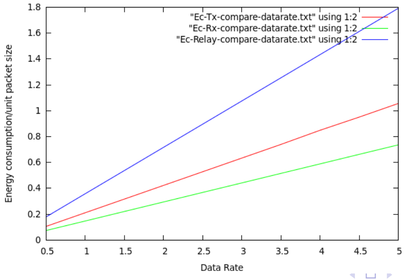
$$E_c = I * V * t_p \tag{1}$$

where E_c= Energy consumed, I= Current, V= Voltage, t_p= time taken to transmit a packet.

Energy consumed at various data rate and packet size

Table: Energy consumed at various data rate and packet size

Data Rate	Packet Size		
	256 bytes	512 bytes	1024 bytes
1 Mbps	0.42 J	0.84 J	1.69 J
5 Mbps	0.08 J	0.17 J	0.34 J
10 Mbps	0.04 J	0.08 J	0.17 J



Energy consumed at various data rate and packet size

From the Fig 3, we can notice that energy consumption is directly proportional to Packet Size and inversely proportional data rate. So we can represent the energy consumption E_c as

$$E_c = \frac{Packetsize}{datarate} \tag{2}$$

using equation (2) in equation (1), we can rewrite the energy consumption equation considering the data rate *dr* and packet size *ps* of a node $E_c(ps, dr)$ as,

$$E_c(ps, dr) = \frac{I * V * T_p * P_s}{d_r} \tag{3}$$

Considering node transmission mode

Consider a single node n in a set of N nodes $n_i \in \{N\}$ Where i is the number of nodes. We have $n_{ik} \in \{N\}$ where ik is the traffic from $n_i \rightarrow n_k$ there exists n_j as a relay node. Energy consumed to Transmit packet from node n_i to node n_j can be given by,

$$E^{T_X}_{c(i \rightarrow j)}(ps, dr) = T_p * E_c(ps, dr) \tag{4}$$

where T_p= transmit power in mA.
Energy consumed to Receive packet from node n_k to node n_i can be given by,

$$E^{R_X}_{c(k \leftarrow i)}(ps, dr) = R_p * E_c(ps, dr) \tag{5}$$

where R_p = receive power in mA.
Energy consumed to Relay packet from node n_i to node n_k can be given by,

$$E^{R_{EL}}_{c(i \rightarrow j \rightarrow k)}(ps, dr) = E^{R_X}_{c(i \rightarrow j)}(ps, dr) + E^{T_X}_{c(i \rightarrow j)}(ps, dr) \tag{6}$$

Total energy consumed by node which involve in transmission can be represented as

$$E_c^{tot}(ps, dr) = E_c^{T_X}(ps, dr) + E_c^{R_X}(ps, dr) + E_c^{R_{EL}}(ps, dr) \quad (7)$$

In general,

$$E_c^{tot}(ps, dr) = N \sum_{i=1}^{n} (E_c^{T_X}, E_c^{R_X}, E_c^{R_{EL}}) \quad (8)$$

where N= total no of transmission occurred.

Calculating remaining energy of a node

The remaining energy of a node can be calculated by using the below equation

$$R_E = I_E - E_c^{tot} \tag{9}$$

where R_E= Remaining Energy, I_E = Initial Energy, E_c^{tot}= total energy consumed by the node at time t_n given n is the simulation time.

Fixing minimum energy required (threshold) by node during transmission

Using equations 4, 5 and 6, we define the minimum energy required by node considering node's transmission from node n_i to node n_k via n_j when it is:

a. Transmitting a packet size of *ps* bytes and data rate of *dr* Mbps from node n_i node n_j.

$$R_{ET}^{Tx}(ps, dr) = E_{c(i \to j)}^{Tx}(ps, dr)J \qquad (10)$$

where R_{ET}^{Tx}= Minimum energy required by a node to transmit a one packet from node n_i node n_j.

b. Receiving packet size of *ps* bytes and data rate of *dr* Mbps by a node n_k from node n_i.

$$R_{ET}^{Rx}(ps, dr) = E_{c(k \leftarrow i)}^{Rx}(ps, dr)J \qquad (11)$$

where R_{ET}^{Rx}=Minimum energy required by a node n_k to receive a one packet from node n_i.

Set power save mode base on energy constraints and transmission mode

The following equation defines the state of *AE* and *TM*.

$$TransmissionMode(TM) = \begin{cases} 1, & \text{if } n = \{T_X, R_X, R_{EL}\} \\ 0, & \text{if } n = \text{ no transmission} \end{cases} \quad (13)$$

and

$$AvailableEnergy(AE) = \begin{cases} 1, & \text{if } R_E \geq R_{ET} \\ 0, & \text{if } R_E \leq R_{ET} \end{cases} \quad (14)$$

where R_{ET} = Remaining Energy Threshold and R_E = Remaining Energy of a node.

Tabular representation of PSM states

Table: PSM States

Available Energy \ Transmission Mode	TM=1			TM=0
	R_X	T_X	R_{EL}	
AE=1	A	A	A	LS
AE=0	DS	DS	DS	DS

A= Active, LS= Light Sleep and DS= Deep Sleep.

Proposed equation to define PSM states

Considering available energy of a node and node's involvement in transmission we can define PSM state as,

$$PSM(S) = \begin{cases} A, & \forall n = \{TM == 1 \&\& AE == 1\} \\ LS, & \forall n = \{TM == 1 \&\& AE == 1\} \\ DS, & \forall n = \{TM == 0/1 \&\& AE == 0\} \end{cases} \quad (15)$$

where A= Active mode, LS=Light Sleep mode and DS=Deep Sleep mode

The above equation 15 is a proposed EAPSM mathematical model which schedules PSM of a node.

Packet Delivery Ratio

- Conventional PSM, the PDR of a network considering packet size and data rate can be given as

$$PDR(i, j, ps, dr) = \frac{\sum_{n=i}^{j} \left(\frac{\sum P_{rec}}{\sum P_{sen}} \right) (ps, dr)}{N} \quad (16)$$

where i is the source node, j is the destination node, ps is packet size, dr is the data rate, P_{rec} is number of packets received by node, P_{sen} is number of packets sent by node and N is the number of node involved in transmission.

Packet Delivery Ratio

- The Proposed EAPSM model for PDR can be given by considering energy constraints

$$PDR(i,j,ps,dr,s) = \frac{\sum_{n=i}^{j} psm(s)\left(\frac{\sum P_{rec}}{\sum P_{sen}}\right)(ps,dr)}{N} \qquad (17)$$

where ps is packet size, dr is the data rate, P_{rec} is number of packets received by node, P_{sen} is number of packets sent by node and N is the number of node involved in transmission. $psm(s)$ is determined by equations 15, 13 and 14.
This will ensure that STA changes its state from Light sleep only when it has sufficient energy to be involved in transmission. This will result in high PDR and increases QoS of network.

Outline

State diagram of proposed model

Consider a set of states
$P = \{Acitve, LightSleep, DeepSleep\}$
$TM = \{R_X, T_X, R_{EL}, Null\}$
$AE = \{High, Low\}$
Where P is an outcome PSM state based on two observations: Transmission Mode (TM) and Available Energy (RE) of a node. The probability of change in state of PSM is as shown in below state diagram.

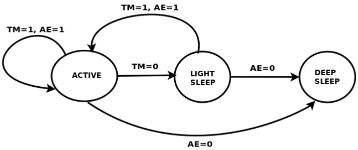


Figure: State diagram of EAPSM

Probability of node being in Active state

$$P(S = A \mid (TM == 1 \cap AE == 1)) = \frac{P((TM == 1 \cap AE == 1)|S = A)P(S = A)}{P(TM == 1 \cap AE == 1)} \quad (18)$$

where,

- $P(S = A)$ is the probability of PSM state in Active.
- $P(TM == 1 \cap AE == 1)$ is the probability of node being in Transmission Mode and High Available Energy.
- $P((TM == 1 \cap AE == 1)|S = A)$ is the probability of node being in Transmission Mode and High Available Energy given PSM state is Active.
- $P(S = A|(TM == 1 \cap AE == 1))$ is the probability of node being in Active PSM state given node being in Transmission Mode and High Remaining Energy.

Outline

Proposed Algorithms

Algorithm 1 Schedule Power Save Mode

set $I_E = 10J$
set $R_E = 10J$
set $R_{ET}^{RX} = 0.1472J$
set $R_{ET}^{TX} = 0.212J$
set $R_{ET}^{REL} = 0.3584J$
set $TM == 1$, $AE == 1$
for each n in N **do**
  Calculate Available Energy (AE)
  Identify Transmission Mode (TM)
  if $(TM! = 0\&\&AE! = 0)$ **then**
    if $((TM == R_X)\&\&(R_E^{RX} \geq R_{ET}^{RX}) \parallel (TM == T_X)\&\&(R_E^{TX} \geq R_{ET}^{TX}) \parallel (TM == R_{EL})\&\&(R_E^{REL} \geq R_{ET}^{REL}))$ **then**
      PSM(S) == Active
    else
      PSM(S) == Light Sleep
    end if
  else
    PSM(S)== Deep Sleep
  end if
end for

Algorithm 2 Calculate Available Energy

set $I_E = 10$
set $C_E = 0$
$E_{i+1} = E_i + V{*}(t_{i+1} t_i) * I_i$
$R_E = I_E - E_c^{tot}$

Algorithm 3 Identify Transmission Mode

set $R_X = 0$
set $T_X = 0$
set $R_{EL} = 0$
for each n in N **do**
  if $(n == R_X \parallel n == T_X \parallel n == R_{EL})$ **then**
    $TM == 1$
  else
    $TM == 0$
  end if
end for

Outline

Analysis of proposed algorithm

Table: Algorithm Analysis Parameters

Parameters	Values
No. of Nodes	7
Packet Size	256 bytes
Data Rate	2 Mbps
No. of Packets	40
Initial Energy	10 J
Initial PSM Mode	Light Sleep
Initial Transmission Mode	0
Transmission Power	330 mA
Reception Power	230 mA
Energy threshold-Tx	0.21 J
Energy threshold-Rx	0.14 J
Energy threshold-Rel	0.35 J

Working of conventional PSM

Let us consider an example of routing with conventional PSM installed to each node in WMN as shown in Fig. 5

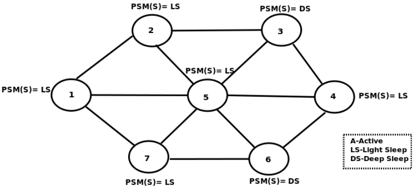


Figure: Example of Routing with conventional PSM installed in WMN

Figure consists of 7 nodes each in different PSM state. Node-1, node-2, node-4, node-5 and node-7 are in Light Sleep mode. Node-3 and node-6 are in Deep Sleep Mode. The initial PSM state of each node is as shown in Table.

Working of conventional PSM

Table: PSM-node's status without transmission

Node	Initial-PSM(S)
1	Light Sleep
2	Light Sleep
3	Deep Sleep
4	Light Sleep
5	Light Sleep
6	Deep Sleep
7	Light Sleep

PSM-node's status with transmission

Table: PSM-node's status with transmission

Node	Initial-PSM(S)	New-PSM(S)
1	Light Sleep	Active
2	Light Sleep	Light Sleep
3	Deep Sleep	Deep Sleep
4	Light Sleep	Active
5	Light Sleep	Active
6	Deep Sleep	Deep Sleep
7	Light Sleep	Light Sleep

PSM-node's status with transmission

Figure shows that packets are transmitted from node-1 to node-4 successfully via node-5.

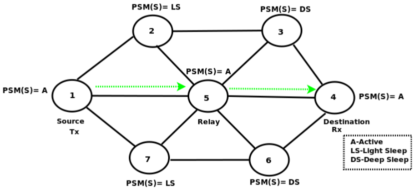


Figure: Example of Routing with PSM conventional installed Packet transmission

Example of Routing with conventional PSM installed showing Packets dropped

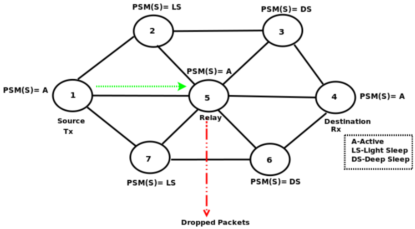


Figure: Example of Routing with conventional PSM installed showing Packets dropped

Working of proposed EAPSM

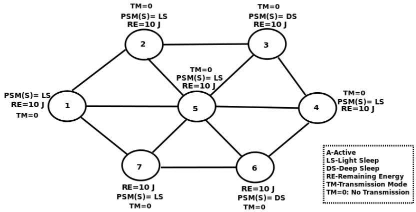


Figure: Example of Routing with proposed EAPSM installed

Initially each node has remaining energy 10J and it is not involved in transmission of packet. It is as shown in Table 6. It shows the initial PSM state of each node. Node-1, node-2, node-4, node-5 and node-7 are in Light Sleep mode. Node-3 and 6 are in Deep Sleep Mode. Available energy of all node is 10J. Since nodes are not involved in transmission initially, Energy consumption is 0J. The PSM state of node is determined using equation 15.

Working of proposed EAPSM

Table: EAPSM-node's status without transmission

Node	Transmission Mode			E_c^{tot}	R_E	Init-PSM(s)
	RX	TX	Rel			
1	×	×	×	0	10	LS
2	×	×	×	0	10	LS
3	×	×	×	0	10	DS
4	×	×	×	0	10	LS
5	×	×	×	0	10	LS
6	×	×	×	0	10	DS
7	×	×	×	0	10	LS

Fixing minimum energy (threshold) required by node during transmission to transmit one packet

Using equations 10 , 11 and 12 , we calculate the minimum energy required by node when it is:

a. Transmitting packet size of 256 bytes and data rate of 2 Mbps

$$R_{ET}^{T_X}(256, 1) = 0.212J \tag{19}$$

where $R_{ET}^{T_X}$= Minimum energy required by node-1 to transmit packet-1 to node-5

b. Receiving packet size of 256 bytes and data rate of 2 Mbps

$$R_{ET}^{R_X}(256, 1) = 0.1472J \tag{20}$$

where $R_{ET}^{R_X}$=Minimum energy required by node-4 to receive a packet-1 from node-5

c. Relay packet size of 256 bytes and data rate of 2 Mbps

$$R_{ET}^{R_{EL}}(256, 1) = 0.3584J \tag{21}$$

EAPSM-node's status with transmission of packet

Table: EAPSM-node's status with transmission of packet

Node	Transmission Mode			E_c^{tot}	R_E	AE	Init-PSM(s)	New-PSM(s)
	RX	TX	Rel					
1	$\times$	$\times$	$\times$	0	10	1	LS	A
2	$\times$	$\times$	$\times$	0	10	$\times$	LS	LS
3	$\times$	$\times$	$\times$	0	10	$\times$	DS	DS
4	$\times$	$\times$	$\times$	0	10	1	LS	A
5	$\times$	$\times$	$\times$	0	10	1	LS	A
6	$\times$	$\times$	$\times$	0	10	$\times$	DS	DS
7	$\times$	$\times$	$\times$	0	10	$\times$	LS	LS

Example of Routing with proposed EAPSM installed showing Packet transmission

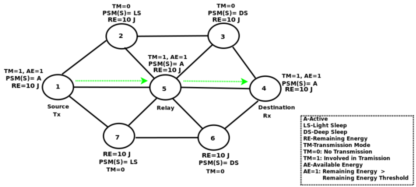


Figure: Example of Routing with proposed EAPSM installed showing Packet transmission

Calculating energy consumed by node during transmission to transmit packet-1

Using equations 4, 5 and 6 , we calculate the energy consumed by node when it is:

a. Transmitting packet size of 256 bytes and data rate of 2 Mbps

$$E^{T_X}_{c(1\rightarrow5)}(256, 1) = 0.21J \tag{22}$$

where $E^{T_X}_{c(1\rightarrow5)}(256, 1)$= Energy consumed by node-1 to transmit packet-2 to node-5

b. Receiving packet size of 256 bytes and data rate of 2 Mbps

$$E^{R_X}_{c(4\leftarrow1)}(256, 1) = 0.14J \tag{23}$$

where $E^{R_X}_{c(4\leftarrow1)}(256, 1)$=Energy consumed by node-4 to receive a packet-2 from node-5

c. Relay packet size of 256 bytes and data rate of 2 Mbps

$$E^{R_{EL}}_{c(1\rightarrow5\rightarrow4)}(256, 1) = 0.35J \tag{24}$$

EAPSM-node's status with transmission of packet-1

Table: EAPSM-node's status with transmission of packet-1

Node	Transmission Mode			E_c^{tot}	R_E	AE	Init-PSM(s)	New-PSM(s)
	RX	TX	Rel					
1	×	✓	×	0.21	9.79	1	LS	A
2	×	×	×	0	10	×	LS	LS
3	×	×	×	0	10	×	DS	DS
4	✓	×	×	0.14	9.86	1	LS	A
5	×	×	✓	0.35	9.65	1	LS	A
6	×	×	×	0	10	×	DS	DS
7	×	×	×	0	10	×	LS	LS

Example of Routing with proposed EAPSM installed showing Packet transmission and Decrease in Remaning Energy

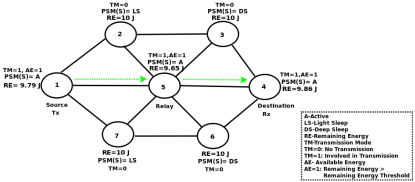


Figure: Example of Routing with proposed EAPSM installed showing Packet transmission and Decrease in Remaning Energy

EAPSM-node's status with transmission of packet-28

Table: EAPSM-node's status with transmission of packet-28

Node	Transmission Mode			E_c^{tot}	R_E	AE	Init-PSM(s)	New-PSM(s)
	RX	TX	Rel					
1	×	✓	×	5.88	4.12	1	LS	A
2	×	×	×	0	10	×	LS	LS
3	×	×	×	0	10	×	DS	DS
4	✓	×	×	3.92	6.08	1	LS	A
5	×	×	×	9.8	0.20	0	A	LS
6	×	×	✓	0.35	9.65	1	DS	A
7	×	×	✓	0.35	9.65	1	LS	A

Example of Routing with proposed EAPSM installed showing Packet reaching successfully to destination by changing PSM state

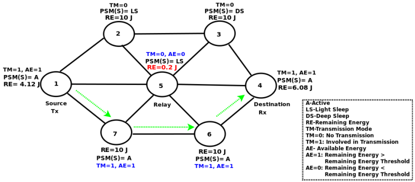


Figure: Example of Routing with proposed EAPSM installed showing Packet reaching successfully to destination by changing PSM state

PDR calculation-Conventional PSM

In our example installed with conventional PSM, we have considered 40 packets to transmit from node-1 to node-4.
The PDR was calculated by using equation 16 for conventional PSM.
Only 27 packets were successfully delivered to destination.
The remaining 13 packets were dropped at node-5 as node was in Active mode to receive packet but failed to forward to destination due to less energy. Since node-5 was in Active mode while forwarding packet 28, the other nodes were not allowed to choose as relay node in network to forward packet to destination.

$$\begin{aligned} PDR(1,4,256,1) &= \frac{1\left(\frac{40}{40}+\frac{27}{40}+\frac{27}{40}\right)}{3} \\ &= 0.79 \end{aligned} \tag{25}$$

Therefore conventional PSM results in 79% of PDR.

PDR calculation-EAPSM model

Considering same example installed with EAPSM, the PDR was calculated by using equation 17 for proposed EAPSM.
In EAPSM, All 40 packets were successfully delivered to destination.
Since node-5 was in Active mode and was having less energy, the PSM state of node-5 is changed from Active mode to Light sleep mode in our proposed EAPSM.
This allowed source node to choose another node as relay node in a network to forward packet to destination.

$$PDR(1,4,256,1,s) = \frac{1\left(\frac{40}{40}+\frac{27}{27}+\frac{13}{13}+\frac{13}{13}+\frac{40}{40}\right)}{5} = 1 \tag{26}$$

Therefore proposed EAPSM results in 100% of PDR.
The results from equations 25 and 26 shows that using our proposed EAPSM model results high PDR compared to conventional PSM.

Outline

Conclusion

- We have proposed a mathematical model to trigger the PSM in WMN
- The model has equations to compute remaining energy, energy consumption and conditions to trigger the PSM.
- We have shown the state diagram and analysed the probabilities of changing the PSM considering the constraints such as remaining energy and node's involvement in transmission.
- It has been found that the proposed model enhance the QoS by the increase of PDR when compared to conventional PSM.

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Future work

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- Considering the dynamic nature of nodes installed with PSM.
- Comparing the analytical and simulated result of proposed model.

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Future work

- Includes the study of network behaviour under NS3.
- Considering the dynamic nature of nodes installed with PSM.
- Comparing the analytical and simulated result of proposed model.