Replicating Cytokines in Modelling Signal Exchange between Nodes in Wireless Mesh Networks

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Abstract— **In recent years wireless mesh network (WMN) technologies and their applications have been actively researched and developed as the promising solution for future wireless mobile networks. Conversely security of WMN is often a secondary reflection in development. In our previous work we proposed Artificial Immune System model to employ in secure routing in WMN. This paper proposes an emerging perception to model danger signal exchange between nodes in WMN by emulating the function of Cytokines in Human Immune System (HIS).**

Index Terms— **Wireless Mesh Networks (WMNs), Artificial Immune System (AIS), Cytokines.**

I. INTRODUCTION

Wireless Mesh Networks (WMNs) are evolving as a future generation wireless mobile networks and bring the dream of connected world into reality. According to 802.11s standardNodes in a mesh network can be divided into four classes, Client or Station (STA), Mesh Point (MP), Mesh Access Point (MAP) and Mesh Portal Point (MPP). Client is a node that requests services but does not contribute in path discovery, Mesh Point (MP) is a node that participates in the mesh operations, Mesh Access Point (MAP) is a MP attached to an access point (AP) to provide services for clients (STA), Mesh Portal Point (MPP) is a MP with additional functionality to act as a gateway between the mesh and an external network. Fig 1 shows WMN architecture according to 802.11s standard.
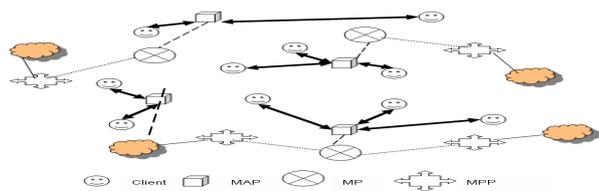

Fig 1: WMN Architecture [adapted [3]]

Further, WMN is dynamically self-organized and self configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among them. Major principles of self-organization can be classified in to four categories specifically local state evaluation, interaction between individuals, negative feedback loop and positive feedback loop. This concept is common to both biological systems and communication systems and the figures 2 and 3 compare the concept of feedback loops for biological system and the feedback loop for WMN system respectively. Positive feedback loop amplifies an effect whereas negative feedback loop controls the system behavior. Any dependencies and global control are prevented by acting upon local information. Moreover, direct and indirect information exchange is used to update local state and interact with the system environment. The self organizing nature of WMN brings many rewards such as low up-front cost, easy network maintenance, robustness, and reliable service coverage and delivers wireless services for extended applications namely real time intelligent transportation systems, spontaneous networking, rural networks, enterprise networking, building automation and security surveillance systems.
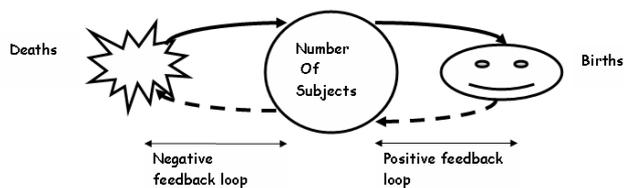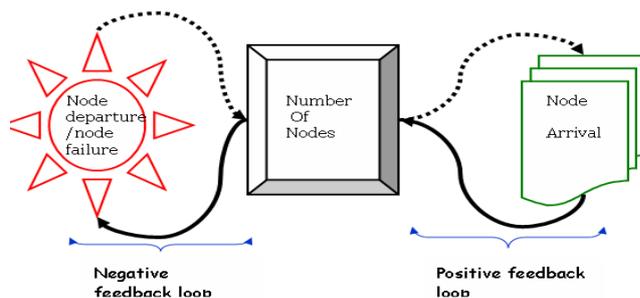

Fig. 2: Feedback loops in biological system

Fig. 3: Feedback loops in WMN system

II. FROM NATURE TO COMMUNICATION ENGINEERING

In spite of recent advances in Wireless Mesh Networking, considerable research is still needed to address the most challenging factor is security. Although there has been a rapid boost in researching security of Wireless Mesh Networks, still they lack efficient and scalable security solutions due to their dynamic and distributed nature of the system. None of the existing key management based techniques are suitable for wireless mesh networks as they are inefficient on an arbitrary or unknown network topology, or not tolerant to a changing network topology or link failures.

In contrast, a great increase in studying biologically inspired system, specifically the rising curiosity in Human Immune System (HIS) stimulates the applicability of HIS concepts in WMN security. Some of the attractive features analogous to the features of WMN include adaptability, distributability, diversity, autonomy and dynamic coverage. Moreover, secure routing functions can be mocked-up by analysing the reaction process of Human Immune System (HIS) against a foreign material [1].

III. MAPPING OF HUMAN IMMUNE SYSTEM ELEMENTS ON TO WIRELESS MESH NETWORK

The elements of HIS can be mapped on to WMN as depicted in Table I. This table shows an improved version of the mapping proposed in our previous work [1].

TABLE 1: MAPPING OF HIS ON TO WMN

HIS	WMN
Body	The entire WMN system
Self-Cells	Well behaved network resource nodes
Non-Self Cells	Corrupted or well-behaving but unauthorized nodes inside the network or any external input either friendly or malicious. Inactive or non participating nodes
Antigen	Possible cause of interruption or anomalies or danger to the network
Antibody	Recovery or protection actions for the node in danger possibly caused by antigen
Cytokines	Error messages or danger signals or events communicated between nodes

IV. DANGER THEORY AND WMN SECURITY

After having mapped the HIS and WMN, various Artificial Immune System (AIS) models were analysed in our previous work [1] to identify the complete model to deploy in WMN environment. Among other AIS models we have proposed Danger theory. The critical tenet of conventional immunology is the distinction between "self" and "non-self" cells. An immune response is triggered when the body encounters something "non-self". On the other hand, the central theme of Danger theory is that the immune system responds to danger but not to "non-self". This concept is realistic in WMN environment. Fig 4 illustrates self – non self vs. danger-non danger distinction. Also Fig 5 depicts the

model of danger theory which has been adapted to model security of WMN. When a distressed cell sends out a danger signal, a danger zone around itself is formed and antigens in the neighborhood are captured by Antigen Presenting cells. B-Cells with in the danger zone get stimulated and produce antibodies.
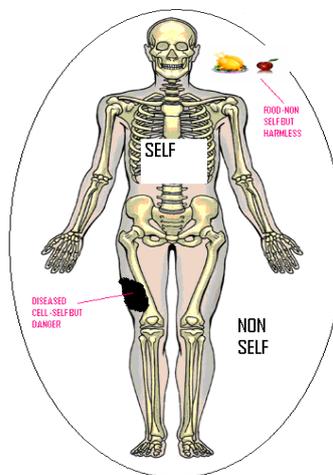

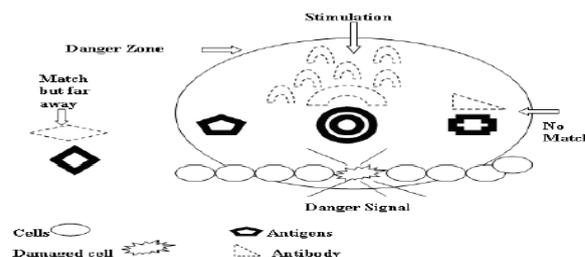Fig 4: Self and non-self cells VS Danger and non-danger [from source [2]]

Fig 5: Model of the danger theory [from source [1]]

V. CYTOKINES AND WMN SIGNALLING

Cytokines play major role in the process of immune response and regulate proper functioning of the immune system [4], [5]. Cytokines are small molecules that act as messengers between cells, produced on demand by active gene transcription and translation by stimulated cells and signal immune cells and other cells to take actions, stimulating or suppressing the immune response [4], [7]. In general, classification of cytokines is based on the structure and/or functions, however different cytokine may have overlapping functions and act together and synergistically modulate target cell functions [5]. Table 2 shows the classification of cytokines adapted from [5], [6].

TABLE 2: CLASSIFICATION OF CYTOKINES

Cytokine family	Members	Biological performance
Interleukins	IL-1 - IL-33	Regulation of cell proliferation and differentiation, immune cell activation/suppression
Interferons	INF- $\alpha,\beta,\gamma,\lambda,\omega,\tau$	Antiviral,

		anti-proliferative, immunomodulation
Tumor necrosis factors	TNF- α, TNF- β	Proinflmmatory, apoptosis
Transforming growth factor β	TGF- β, inhibins, activins, bone morphogenetic proteins	Immunomodulation, development, morphogenesis
Chemokines	C,CC,CXC,CX3 C type chemokines	Leucocyte chemotaxis, angiogenesis/angios tasis, tumor metastasis, HIV infection, polarization of adaptive immune response
Colony stimulating factors	GM-CFS, G-CFS, M-CSF, IL-3	Growth and differentiation of hematopoietic cells
Growth factors	EPO, TPO, EGF, FGF, PDGF	Growth and differentiation of cells

Similarly, we propose that the function of cytokines can be deployed in modelling danger signals in WMN as the Danger signals which signify the state of the mesh network [1] can be issued by the network cells (nodes). Moreover, from the literature the following classification of intercellular communication has been identified.

VI. CLASSIFICATION OF INTERCELLULAR COMMUNICATION

Within endocrinology and the endocrine system, intercellular signalling is subdivided into the following classes [4]:

Endocrine: signals are produced by endocrine cells and travel through the blood to reach all parts of the body.

Paracrine: signals target only cells in the vicinity of the emitting cell.

Autocrine: signals affect only cells that are of the same cell type as the emitting cell.

Juxtacrine: signals are transmitted along cell membranes via protein or lipid components integral to the membrane and are capable of affecting either the emitting cell or cells immediately adjacent.

VII. MAPPING OF HIS INTERCELLULAR COMMUNICATION ONTO NODE COMMUNICATION IN WMN

TABLE 3: MAPPING OF HIS INTERCELLULAR COMMUNICATION ON TO WMN NODE COMMUNICATION

HIS	WMN
Endocrine	Signal produced by a node broadcast to all nodes in WMN
Paracrine	Signal produced by a node transmit to neighbour nodes
Autocrine	Signal produced by a node transmit only to the same kind of node

VIII. CYTOKINE COMMUNICATION NETWORK

The figure below shows the Cytokine communication network adapted from Biocarta. For simplicity a curtailed diagram is illustrated in Fig.6.
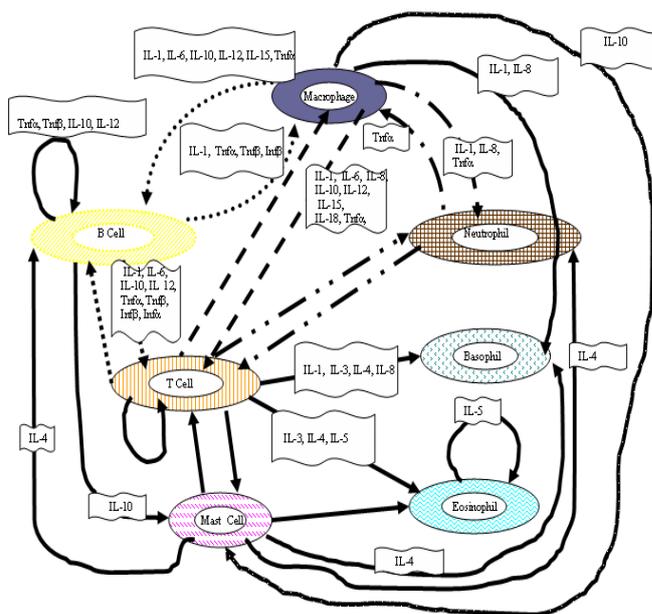

Fig.6: Cytokine Communication Network

T-Cell in the network enhances immune responses by the secretion of specialised factors that activate other cells to fight against infection [10]. The major function of B-Cell is the production of antibodies in response to foreign substance and identifies pathogens when antibodies on its surface bind to a specific foreign antigen [10], [11].Further, B-cell signals other cells to kill or remove foreign substance from the body [10]. Fig.7 illustrates the function of B-cell and T-cell mechanism, adapted from [12]. Moreover, Macrophage is an Antigen Presenting Cell which activates adaptive immune response [8], [10], [11] and Mast Cell belongs to the family of Basophil, Neutrophil and Eosinophil and present near the boundaries between the body and the outside world [9].
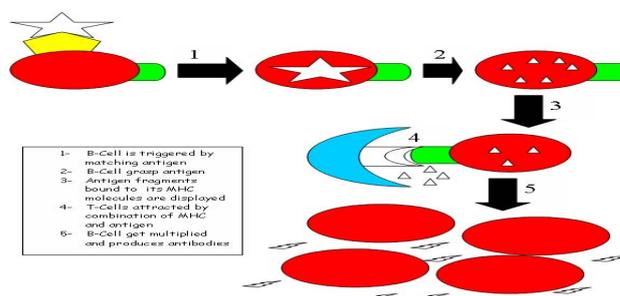

Fig. 7: B-cell and T-cell mechanism

IX. IMMUNE CELL FUNCTIONS MAPPED ON TO WMN NODE FUNCTIONS

Table 4 depicts the developed mapping between Immune cells and WMN nodes.

TABLE 4: MAPPING IMMUNE CELL FUNCTION ON TO WMN NODE FUNCTION

Immune Cells	WMN nodes
T- cell	AP
B-Cell	MAP
Macrophage	STA
Mast Cell	MPP
Recognition of Antigens	Identification of anomalous behaviors
Production of Antibodies	Formulating successful solution to overcome malicious attacks
T-Cell suppression	Eliminate redundant potential Solutions against anomalous behaviors

X. MODEL DIAGRAM AND MATHEMATICAL MODEL OF THE SYSTEM

Based on the mapping in section IX, a modal has been developed and shown in Fig.8
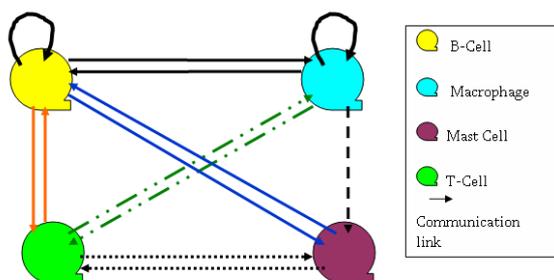

Fig. 8 : Model Diagram

Cytokines engage in the communication among these four nodes are, IL-1, IL-3, IL-4, IL-6, IL-8, IL-9, IL-10, IL-12, IL-13, IL-15, IL-18, Tnfα, Tnfβ, Ifnα, Ifnβ, Ifnγ. Among various approaches differential equations have been used to model WMN system elements and the behavior of the system and Java based agent simulator is employed for simulation.Fig.9 and Fig.10 show the regular network layout and random network layout respectively
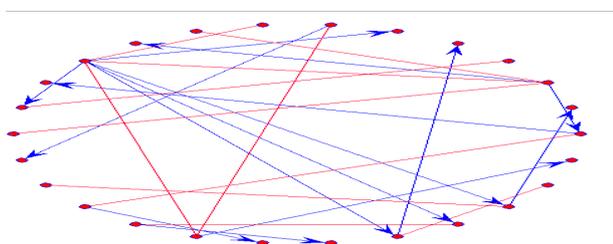

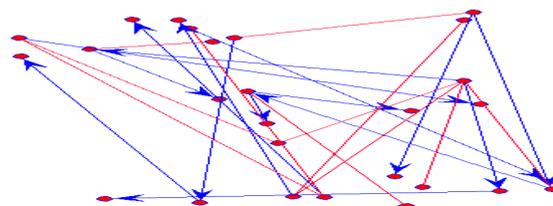Fig. 9: Regular Network layout

Fig.10: Random Network layout

XI. FUTURE WORK

We are continuing the development of mathematical modeling and simulating in Java based agent simulator.

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