M/G/1 QUEUING MODEL AS PART OF A CLOUD GATEWAY FOR MILITARY BASED SENSOR NETWORK APPLICATIONS

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ABSTRACT

Cloud computing, a new paradigm for communication between computers over internet is adopted by defence research organizations through private cloud for offering a variety of services. Since the issues of data security that revolves around military is considered to be so sensitive, military cloud cannot be deployed as a public cloud. Defence operations can be improved in its functional efficiency through cloud computing. Wireless Sensor Networks had been already deployed for many military monitoring applications and information gathering. In this paper, we present an application architecture where military WSN is integrated with defence based private cloud. We propose to apply M/G/1 queuing model with pre-emptive priority service discipline at the cloud gateway to calculate the average waiting time of priority packets and non priority packets in the queue of cloud gateway. We also compare the average waiting time of non priority and priority packets for different arrival rates at the cloud gateway using simulation.

Index Terms: Cloud Computing, Private Cloud, Wireless Sensor Networks, Queuing model, Defence Applications, Pre-emptive priority

I. INTRODUCTION

A holistic approach to provide a variety of applications, platforms and infrastructure as an on-demand service over internet is called as Cloud Computing. In United States, Department of Defence (DoD) already has a well placed and positioned Service Oriented Architecture (SOA). In SOA of DoD, different systems are treated as sets of services. This shall definitely assist DoD to leverage private cloud into their existing architecture. The data that revolves around different systems of defence is confidential and should be highly secured. Hence the type of cloud that should be deployed at DoD is considered to be private cloud. Moreover, the Department of Defence has been asked to reduce their number of data centres
by consolidation process, towards energy conservation [1]. This makes sense for the DoD to adopt and deploy private cloud for its operational efficiency.

In order to increase the scope of defence Cloud’s functions, we consider integrating WSN based defence applications to utilize the services of defence cloud in reaching the data centre resources. A sensing and communication network (sensor network) consisting of a large number of battery powered sensor nodes is deployed for many defence applications such as monitoring infiltrations by enemies at borders, field monitoring within our territory, location identification and direction of movement of regiments. The sensor nodes deployed at war zones transmit both periodical data and event driven data to various resources in the data centres for further action. Data centres are part of the defence cloud. Hence all the packets from the sensor nodes should reach different resources within the data centres through cloud gateway. Cloud gateway should transmit the packet to the appropriate resource for further action depending on the type of service requested, in the packet. Most of the previous research works on enhancing the military operations focussed on efficient deployment and functioning of Wireless Sensor Networks [2,3,4]. In cloud computing, researches were carried out to determine job scheduling system algorithm using queuing models [5]. But our paper is the first work which integrated the capabilities of WSN and cloud computing to improve the efficiency of defence operations. This paper also presents the performance analysis of defence cloud gateway based on the system architecture, using queuing theory, which is first of its kind.

The rest of the paper is organized as following: Section II presents the entire system architecture with the necessary details about WSNs and private cloud adopted for our proposition and analysis. Section III gives the details of the proposed queuing model as part of the defence cloud gateway and the calculation of average waiting time and residual service time of priority and non priority packets in the gateway queue is discussed in section IV. Conclusion and Future Work are presented in section V.

II. SYSTEM ARCHITECTURE

The primary divisions of our system architecture are wireless sensor network and private cloud (defence cloud). First let us describe the architecture of WSN deployed for defence applications monitoring infiltrations by enemies at borders, location identification and direction of movement of regiments. Through distributed coordination, WSN, are envisioned to enhance situational awareness and improve the effectiveness of military operations.

In our architecture, we classify the deployed nodes into three categories based on their capabilities and features. Category 1 nodes are deployed within our territory to gather information about environment, and regiment. This category 1 nodes are grouped into clusters and each cluster will have a category 2 node acting as a sensor network gateway to transfer the sensed information transmitted from category 1 nodes to the defence cloud gateway. The sensor Network gateway node (category 2) is similar to fusion node [2] in features and capabilities. The nodes of third category are deployed for border patrol.
These nodes are not grouped into clusters but every category 3 node will transmit periodical lower priority packet and event driven higher priority packets with information on enemy movements and infiltration to the defence cloud gateway using long haul wireless transmissions (high frequency) or via a satellite link [3]. We assume that the entire sensor nodes can identify neighbours within communications range and configure themselves into an adhoc network. Even category 1 sensor nodes can associate themselves with the closest gateway (category 2 node) to become a member of cluster.

This makes the entire sensor network self configurable, and self healing in nature as required by military applications [2,3].

**Fig 1. System Architecture**

The second division of our architecture is private cloud. Private clouds offers various advantages of public clouds services but without the concern of data security.[6]. Cloud gateway consists of an application component called WSN virtualization manager [7]. This component is divided into three sub components namely (i) adapter abstraction, (ii) data processing and interpretation and (iii) command interpretation and processing [7].

Information regarding battle field situation awareness and other military operations from category 2 node and category 3 node reaches cloud gateway in the form of priority packets (higher priority) and non priority packets (lower priority). Cloud gateway receives packets in the form of raw byte stream from the...
communications port and forms a raw packet out of it. The packets are queued up in buffer for further processing.

For the queued packets at cloud gateway, we propose to employ appropriate queuing model (discussed in section III) for servicing of packets.

III. PROPOSED QUEUEING MODEL FOR CLOUD GATEWAY

Military WSNs can transmit mission critical packets (such as category 3 nodes at borders) in case of any event and packets containing periodical information about location of regiments and their direction of movement. We can classify packets based on their required priority for processing into high priority and low priority (non priority) packets.

![Fig 2. Queuing Model based on our system](image)

Hence we say that packets of higher priority belong to class 1 and rest of the packets belongs to class 2. When cloud gateway is servicing a class 2 packet during the arrival of class 1 packet, it should suspend its service in order to take the class 1 packet for servicing.

We assume the arrival of both classes of packets to be independent, of each other and to follow a Poisson process. The service time distribution of cloud gateway shall follow general distribution. This is due to the fact that packets generated for different service requests in the WSN contain different payload (priority packets shall have increased payload than non priority packets). Hence the service time distribution of cloud gateway is assumed to follow general distribution. In addition to the above discussion, we also assume the presence of only one server to process and transfer the packet appropriately into the cloud.
So based on the above requirements of our defence cloud and defence WSN, We apply M/G/1 queuing model with pre emptive priority service discipline to the packets that arrive from WSN at cloud gateway for its performance analysis. Let us denote the priority of different packets with the alphabet “k”.

- k=1, denotes higher priority packets
- k=2, denotes lower priority packets (normal packets)

For Priority Packets (k=1)

1. \( N_q^1 \) = Average No. of priority packets in queue
2. \( W_1 \) = Average waiting time for priority packet in queue
3. \( e_1 = \frac{\lambda_1}{\mu_1} \) = system utilization for priority packet
   where \( \lambda_1 \) = arrival rate of priority packet,
   \( \mu_1 \) = departure rate of priority packet
4. \( R_1 \) = Mean residual time of priority packet
5. \( T_1 \) = Average waiting time for priority packet in system

Mean residual time (\( R_k \))= If customer “j” is already being served when “k” arrives, “\( R_k \)” is the remaining time until j’s service time is complete.

I. **CALCULATION OF W_1:**

Based on Pollaczek-Khinchin(P-K) formula [8], we have,

\[
W_1 = R_1 + \frac{1}{\mu_1} N_q^1 \quad \text{……….. (1)}
\]

Applying Little’s Theorem [8], we get,

\[
N_q^1 = \lambda_1 W_1 \quad \text{……….. (2)}
\]

Using (2) in (1), we get,

\[
W_1 = R_1 + \frac{\lambda_1 W_1}{\mu_1} = R_1 + \rho_1 W_1
\]

Therefore, \( W_1 = \frac{R_1}{1-\rho_1} \quad \text{……….. (2a)} \)

Also Mean Residual service time in general for any packet can be obtained from the following equation

\[
R_k = \sum_{i=1}^{k} \frac{\lambda_i X_i^2}{2} \quad \text{……….. (3)}
\]

Where \( X_i^2 \) = second moment of service time

\[
\bar{X}_i^2 = E \{X^2\}
\]
\[ \bar{X}_i = \text{E}\{X_i\} = \frac{1}{\mu_i} = \text{Average service time} \]

Using (3), we obtain mean residual time of priority packet as
\[ R_1 = \frac{\lambda_1 \bar{X}_i^2}{2} \] .......................... (4)

Substitute \( R_1 \) in (2a) using (4),
We get,
\[ W_1 = \frac{\lambda_1 \bar{X}_i^2}{2(1-\rho_1)} \] ......... (5)

II. CALCULATION OF \( T_1 \):

In the calculation of average waiting time \( (T_1) \) of priority packet in the system, we have two different components namely,

a. Average service time of priority packet \( (\frac{1}{\mu_1}) \)
b. Average waiting time of priority packet in queue \( (W_i) \)
\[
W_1 = \frac{R_1}{(1-\rho_1)}
\]
\[
T_1 = \left(\frac{1}{\mu_1}\right) + \frac{R_1}{(1-\rho_1)}
\]
\[
= \frac{1}{\mu_1}(1-\rho_1) + R_1
\]

For non priority packets (k=2):

a. \( N_2 \) = Average No. of non priority packets in queue
b. \( W_2 \) = Average waiting time for non priority packet in queue
c. \( \lambda_2 \) = arrival rate of non priority packet,
\( \mu_2 \) = departure rate of no priority packet
d. \( R_2 \) = Mean residual time of non priority packet
e. \( T_2 \) = Average waiting time for non priority packet in system

Based on Pollaczek-Khinchin(P-K) formula, we have,
1. \[ W_2 = \frac{R_2}{(1-\rho_1-\rho_2)} \]
Where, \[ R_2 = \frac{\lambda_1 \bar{X}_1^2 + \lambda_2 \bar{X}_2^2}{2} \]
2. Average Service Time of non-priority packet = \( \frac{1}{\mu_2} \)

3. \( T_2 = \frac{\left( \frac{1}{\mu_2} \right)(1-\rho_1-\rho_2)+R_2}{(1-\rho_1)(1-\rho_1-\rho_2)} \)

IV. PERFORMANCE ANALYSIS

Based on the queuing model given in section III, we now analyze how average waiting time of priority and non priority packets vary based on the arrival rate of packets.

Area covered by the sensor network = 1000mX1000m

The various parameters utilized in the analysis based on queuing theory and simulations of the queuing model are:

The size of an uncompressed video sample i.e., frames in QCIF format (144*176) is approximately 25 KB [9]. Size of priority packets = 9KB (for a typical high resolution compressed video)

1. Size of non priority packets = 512 bytes (for a typical normal resolution compressed image)
2. Arrival rate of priority packets = 5 packets/sec to 15 packets/sec
3. Arrival rate of non priority packets = 1 packet/sec to 10 packet/sec
4. Data rate at cloud gateway = 2Mbps

The following graphs (Fig.3 & Fig.4) depicts the behaviour of priority packets and non priority packets in terms of average waiting time in system by simulation using Java Modelling tools (JSimGraph) [10].

In Fig.3, the x-axis of the graph provides the arrival rate of priority packets and y-axis of the same provides the average waiting time of non priority packets. The origin of the graph is assumed to start at the arrival rate of 5 packets/sec.

It is quite evident from figure 3, that the average waiting time of non priority packets in the system increases as the arrival rate of priority packets increases in the system. This is well in accordance with the mathematics presented in section III.
Figure 4 clearly shows that, the average waiting time of priority packets in the system for different arrival rates of the same based on simulation. The x-axis of the graph provides the arrival rate of priority packets and y-axis of the same provides the average waiting time of priority packets. The origin of the graph is assumed to start at the arrival rate of 5 packets/sec.

Fig. 4. Average waiting time of Priority packets
V. CONCLUSION AND FUTURE WORK

In this paper, we integrated the use of wireless sensor networks with the defense based private cloud to provide differentiated services. We proposed to apply M/G/1 queuing model with pre-emptive priority service discipline at the cloud gateway to calculate the average waiting time of priority packets and non priority packets in the queue of cloud gateway. We also showed through simulations that average waiting time of priority packets for different arrival rates at the cloud gateway is lesser compared to the non priority packets with the same arrival rates at the cloud gateway. To improve the scope of the research paper, we plan to include more than one server to service packets that are transmitted from wireless sensor networks to cloud gateway, which shall reduce the average waiting time of both priority and non priority packets in the system as well as in the queue.

VI. REFERENCES


