A TRUST MODEL MECHANISM BASED ON QUALITY OF SERVICE TO REDUCE ENERGY CONSUMPTION IN THE INTERNET OF THINGS NETWORK

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ABSTRACT

The Internet of Things (IoT) is a network of connected devices that have emerged as a promising technology to handle small network-based devices. In recent years, adoption of this relatively new technology has grown immensely. The energy consumption for IoT devices is regarded as one of the most critical factors affecting IoT networks' lifespan. Quality of Service (QoS) is considered one of the leading research concerns in IoT networks. Communication between IoT devices needs a suitable and reliable service model to meet the requirements of IoT applications to handle the levels of QoS and maximize network lifespans. Therefore, this study aims to propose a trust model mechanism to provide different levels of QoS (QoST-IoT) and maximize IoT network lifespans. The QoS trust model includes four main steps. The first step is trust level calculation, which is calculated for each of the IoT nodes to find the trust level. Then, in the second step, query trust, the IoT node sends the trust values of various components to the cluster head (CH). The third step involves the clustering of the IoT nodes. Subsequently, the fourth step deals with the trust level update. The experiments conducted in this study revealed that the proposed QoS trust model mechanism (QoST-IoT) reduced the energy consumption compared to the trust model mechanisms previously proposed in the literature. The results of the first simulation round showed that the QoST-IoT outperformed the security & trusted devices in the context of IoT (STD-IoT) by 41.2%, trust-based adaptive security in IoT (TAS-IoT) by 43.7%, and the context-aware and multiservice approach in IoT (Context-IoT) by 45.2%. In addition, the second simulation round showed that the QoST-IoT consumed less energy than STD-IoT by 47.5%, TAS-IoT by 50.5%, and Context-IoT by 53.8%. The findings of this study extend the understanding of designing a QoS trust model with energy consumption reduction for IoT networks, which could be beneficial for researchers, IoT developers, and policymakers.

ABSTRAK

Internet perkara (IoT) merupakan rangkaian peranti yang disambungkan telah muncul sebagai teknologi yang mengendalikan peranti berasaskan rangkaian kecil. Penggunaan teknologi baru ini telah berkembang dengan pesat sejak beberapa tahun yang lalu. Tenaga yang digunakan untuk peranti IoT dianggap sebagai salah satu faktor yang kritikal dan mempengaruhi jangka hayat rangkaian IoT. Kualiti perkhidmatan (QoS) dianggap sebagai salah satu kebimbangan penyelidikan terkemuka dalam rangkaian IoT. Komunikasi antara peranti IoT memerlukan model perkhidmatan yang sesuai dan boleh dipercayai untuk memenuhi keperluan aplikasi IoT. Ia juga perlu untuk mengendalikan tahap QoS dan memaksimumkan jangka hayat rangkaian. Oleh itu, kajian ini mencadangkan mekanisme model amanah untuk menyediakan tahap QoS (QoST-IoT) yang berbeza dan memaksimumkan jangka hayat rangkaian IoT. Model amanah QoS merangkumi empat langkah utama. Langkah pertama adalah pengiraan tahap untuk mencari tahap kepercayaan untuk setiap nod IoT. Seterusnya, dalam langkah kedua, tahap kepercayaan pertanyaan ditetapkan untuk membolehkan nod IoT menghantar nilai kepercayaan pelbagai komponen kepada ketua kluster (CH). Langkah ketiga melibatkan kluster nod IoT. Seterusnya, langkah keempat berkaitan dengan pengemakinian tahap kepercayaan. Ujikaji yang dijalankan dalam kajian ini menunjukkan mekanisme model amanah QoS (QoST-IoT) yang dicadangkan dapat mengurangkan penggunaan tenaga berbanding mekanisme model amanah yang dicadangkan dalam ulasan literatur sebelum ini. Hasil pusingan simulasi pertama menunjukkan bahawa QoST-IoT mengatasi keselamatan dan peranti yang dipercayai dalam konteks IoT (STD-IoT) sebanyak 41.2%, keselamatan penyesuaian berasaskan kepercayaan dalam IoT (TAS-IoT) sebanyak 43.7%, dan pendekatan konteks dan pelbagai perkhidmatan dalam IoT (Context-IoT) sebanyak 45.2%. Di samping itu, pusingan simulasi kedua menunjukkan bahawa QoST-IoT menggunakan kurang tenaga daripada STD-IoT sebanyak 47.5%, TAS-IoT sebanyak

50.5%, dan Context-IoT sebanyak 53.8%. Penemuan kajian ini memperluaskan pemahaman dalam merancang model kepercayaan QoS dengan mengurangkan penggunaan tenaga untuk rangkaian IoT, yang boleh memberi manfaat kepada penyelidik, pemaju IoT, dan pembuat dasar.

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LIST OF SYMBOLS

C_T	-	Communication Trust
C_1	-	The first cluster centroid
C_2	-	The second cluster centroid
C_3	-	The third cluster centroid
C_4	-	The fourth cluster centroid
D_1	-	The distance between IoT node and centroid for the first cluster
D_2	-	The distance between IoT node and centroid for the second cluster
D_3	-	The distance between IoT node and centroid for the third cluster
D_4	-	The distance between IoT node and centroid for the fourth cluster
DC_x	-	The proportion of time that a corresponding component requires
D_T	-	Delay Trust
Enr_{Cons,t_0}	-	The energy consumed at t_0
Enr_{Cons,t_1}	-	The consumed energy at t_1
Enr_{Cons_avg}	-	The average of energy consumed
Enr_{Idle}	-	The energy consumed in idle state
Enr_{Min}	-	The minimum energy consumption node
Enr_{Rem,t_0}	-	The remaining energy at t_0
Enr_{Rem,t_1}	-	The remaining energy at t_1
Enr_{Rem_Avg}	-	The average of energy remaining

En_{send}	-	The energy consumed in sending data
En_{sleep}	-	The energy consumed in sleep state
E_T	-	Energy Trust
E_{Ts}	-	The energy consumed is transition state
$E_{Ts\_ch(s)}$	-	The energy consumption of one-time state transition
F_{β}	-	The number of failed transmission between any node during β and any other node
$F_{x,y}$	-	The total number of unsuccessful interactions of node *x* with node *y*
I_{Avg}	-	The average current consumption
I_{Idle}	-	The electric current in idle state
$I_{End(s)}$	-	The end current
$I_{Int(s)}$	-	The initial current
$T_{Int_{end(s)}}$	-	The time interval for the state transitions from the initial states to the end state
I_{Max}	-	The highest current
I_{Mon}	-	The electrical current in monitoring state
I_{Sleep}	-	The electric current in sleep state
J	-	Joule
k	-	The number of communication transaction
L_i	-	The size length
N_{Rx}	-	The total number of receiving packets
$N_{Ts\_ch(s)}$	-	The frequency of state transition
N_{Tx}	-	The total number of the sending packets
$P_{End(s)}$	-	The power of end state
P_{Idle}	-	The power in idle state
$P_{Int(s)}$	-	The power of initial state transition
P_{Rx}	-	The power in receive state
P_{Sleep}	-	The power in sleep state

P_T	-	Dependability Trust
P_{Tx}	-	The power in send data state
R	-	The data transferring rate
S_β	-	The number of successful transmission between node during β and any other node
$S_{x,y}$	-	The total number of successful interactions of node *x* with node *y*
T_{Max}	-	The battery life
T_{Min}	-	The minimum time
Tx_β	-	The amount of data sent
V_b	-	The working voltage
Δt	-	Time window

LIST OF ABBREVIATIONS

4G	-	fourth generation
6lowpan	-	IPv6 over Low -Power Wireless Personal Area Networks
AEC	-	Average of Energy Consumption
AER	-	Average of Energy Remaining
AODV	-	Ad-hoc On-demand Distance Vector
API	-	Application Programming Interface
CH	-	Cluster Head
Context-IoT	-	Context-aware and multi-service trust management system for the IoT
CPS	-	Cyber Physical Systems
CPU	-	Central Processing Unit
DARPA		Defense Advanced Research Projects Agency
DBSCAN	-	Density-Based Spatial Clustering of Applications with Noise
GUI	-	Graphical User Interface
ICT	-	Information and Communication Technologies
IEEE	-	Institute of Electrical and Electronics Engineers
IETF	-	Internet Engineering Task Force
IoT	-	Internet of Things
IP	-	Internet Protocol
ISO	-	International Organization for Standardization
ITU	-	International Telecommunications Union
LTE	-	Long Term Evolution
MAC	-	Media Access Control
MANET	-	Mobile Ad hoc Network

MENR	-	Minimum Energy Node Remaining
MIT	-	Massachusetts Institute of Technology
NIC	-	National Intelligence Council
NS2	-	Network Simulator
OBUs	-	On-Board Units
OSI		Open Systems Interconnection
P2P	-	Peer-to-Peer
QIoTS	-	Quality of IoT services
QoD	-	Quality of Data
QoI	-	Quality of Information
QoS	-	Quality of Service
QoST-IoT	-	Quality of Service Trust Model for IoT network
RFID	-	Radio Frequency Identification
SIoT	-	Social Internet of Things
SLA	-	Service Level Agreement
SN	-	Social Networks
STD-IoT	-	Security and Trusted Devices in the Context of the IoT
STDV	-	Standard Deviations
TAS-IoT	-	Trust-based Adaptive Security approach for the IoT
TCP	-	Transmission Control Protocol
UDP	-	User Datagram Protocol
UMTS	-	Universal Mobile Telecommunications System
Wi-Fi	-	wireless fidelity
WSN	-	Wireless Sensor Network
WLANs	-	Wireless Local Area Networks

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CHAPTER 1

INTRODUCTION

1.1 Background

The Internet of things (IoT) is a concept that involves different objects and communication mechanisms to exchange data between smart devices. IoT covers several academic discipline domains that encompass a wide range of topics related to technical issues, including semantic queries and routing protocols, and it combines technical and social issues like usability, security, and privacy within the business domain [1]. Recently, the term 'IoT' has become more descriptive of a vision where every device can connect to the Internet and exchange data [2]. IoT is considered fundamental for the future, where it presents opportunities for various innovations and new services. However, all these devices need to be connected to a single network to communicate and can work in unprotected and widely-spread environments, thus leading to major QoS and security challenges [3].

IoT adoption has prompted the evolution of a new domain of network applications in which both existing and potential IoT applications are equally diverse [4]. IoT applications can cover a comprehensive combination of fundamental and secondary fields, including personal health monitoring, environmental/industrial process monitoring, and control that can be applied to smart cities, traffic, agriculture, smart spaces, etc. [5]. Figure 1.1 displays examples of IoT applications.

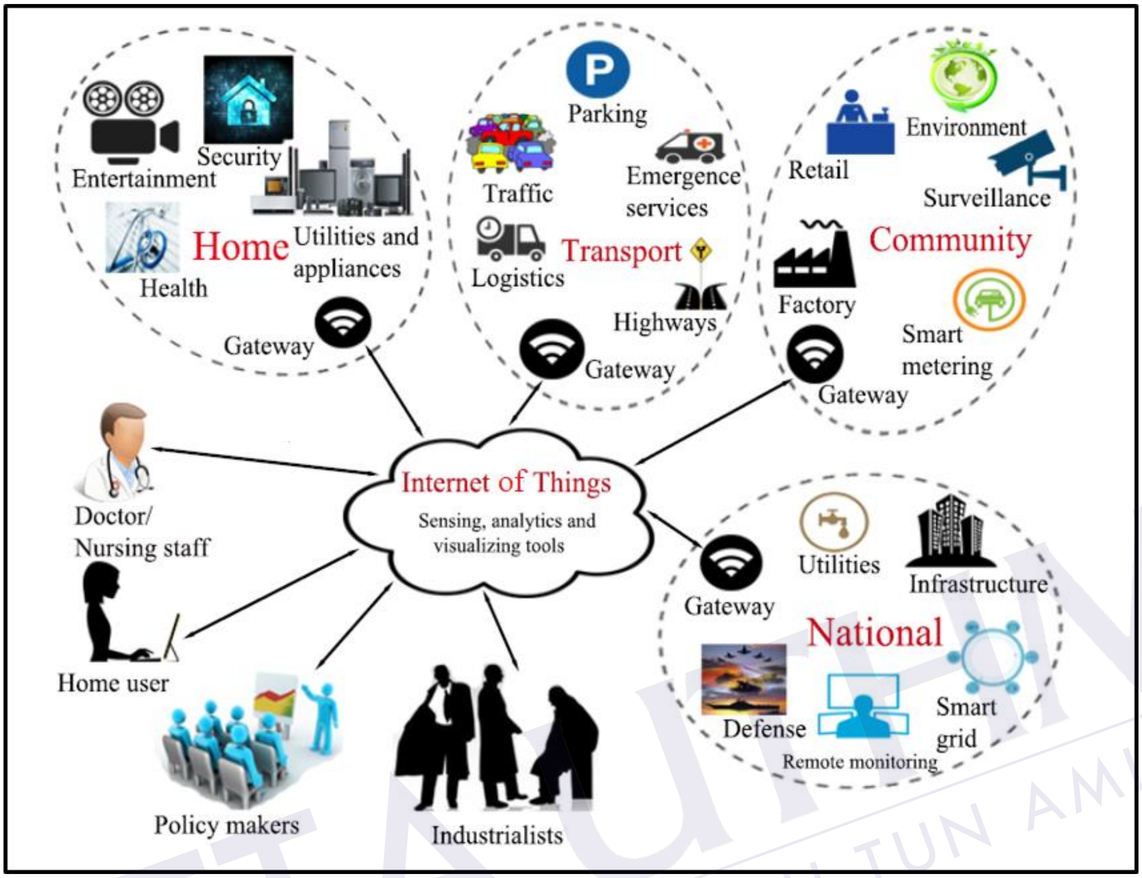

Figure 1.1: IoT network [6]

Providing reliable and efficient data communication for an extensive application range for compliance with a wide range of often-contradicting requirements in a way that includes the required technologies and components is a complex task [7], [8]. IoT also requires a clear architecture and standardization to identify how this unique technology can be implemented. It also needs a precise mechanism through which IoT devices can communicate with each other securely and reliably [9].

An efficient service oriented IoT system needs to meet three conditions: 1) being capable of searching for and discovering services, 2) having specific service categories, and 3) the implementation of composing services. A service in IoT can be specified by considering its capabilities, including data functionalities, communication abilities, interoperability, ability to use the related data, and interactions. In addition, there is a need for devices that can aid in IoT system implementation to satisfy the requirements of particular applications and end-user systems [10]. In some research papers, various categories of resources, search, and discovery have been identified as some of the research issues regarding the service-oriented architectures in IoT [11].

The quality of service (QoS), as a non-functional component, is the capacity of various service providers and structures to provide satisfactory services. Because of the heterogeneous design of IoT, the overall QoS in IoT should support multiple service providers such as sensors, network services, cloud services, and services using various activated technologies and IoT components [12]. Implementing a set of QoS parameters with enabling technologies and service providers depends on the IoT application domain. For instance, QoS parameters for radio frequency identification (RFID) may not apply to wireless sensor networks (WSNs).

The QoS system and QoS architectures derived and defined by different research groups and academic organizations rely on thorough research and service comprehension, message/data classification, enabling technologies, application domain areas, and interactions between these modules. Achieving an optimized QoS would involve implementing the QoS schemes/methods and applying algorithms to enhance or maximize one or more of the relevant service quality parameters [13].

QoS is considered one of the most critical networking issues and has received substantial attention from researchers' regarding both wired and wireless networks [14]. IoT presents various QoS requirements that do not seem to exist in conventional homogeneous wireless and wired networks. A built-in QoS guarantee is required for providing a reliable end-to-end intelligent system that meets the requirements for a complete acquisition transmission interpretation action loop. Therefore, different network mechanisms and protocols need to be developed for IoT.

The central Internet Engineering Task Force (IETF) activities in QoS have mainly concentrated on defining end-to-end QoS protocols, including resource reservation mechanisms. Chander and Kumar [15] focused on the interface-based involvement and the interference implications of wireless networks. The IoT networking environment is intensely characterized by network heterogeneity. Heterogeneous networks have a multi-service feature that enables more than one specific service or application, resulting in multiple traffic types over the selected network. The network traffic can generally be divided into different classes according to the prevailing requirements of bandwidth, delay-sensitive inelastic traffic, throughput, and delay-tolerant elastic traffic [16]. For example, a study by Saha *et al*. [17] stated that a QoS requirement should not be compromised to support all applications through a single network. Henceforth, the QoS requirements are principally deliberated on and defined according to their dedicated network architecture and relevant applications.

In networks, applications have different performance requirements for end-to-end latency, available bandwidth, number of dropped packets, and jitter variation. For example, voice applications require specific delay limitations. On the other hand, file sharing requires only a best-effort protocol. The term QoS has various implementations that correspond with the open systems interconnection (OSI) layers. QoS can be maintained in terms of data and packet loss rates on wireless links at the physical layer. However, in the media access control (MAC) layer, QoS is measured by the ability of nodes to transmit data packets successfully. In the internet protocol (IP) layer, the QoS for a specific route is mainly measured based on the QoS metrics for each hop along the path [18].

Collecting and transmitting data consume a significant amount of power, which is critical in relation to the limited battery power of hardware elements. The more data are obtained and analysed, the more accurate the retrieved information is, but, at the same time, more energy is consumed. Because of energy constraints, a trade-off between information quality extracted and energy consumption by IoT systems is required. In addition, the life of any IoT resource depends on energy availability, and energy loss affects the entire area under surveillance. There is also a clear need for long-term energy consumption and the efficient operation of IoT systems [19].

The installation of billions of IoT devices in homes, factories, and offices worldwide indicates the growing popularity of this efficient technology. It provides the means for wireless transceivers to connect many different sensors to the Internet for remote control of other electronic equipment. For example, it allows users to connect to a heater or air conditioner to adjust the temperature of a family room using a cell phone as a controller from some distance. Often these IoT sensors are “set and forget” devices intended to run for long periods of time on small batteries at low voltages and currents.

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APPENDIX A

LIST OF PUBLICATIONS

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