

## Logistic Regression Trust—A Trust Model for Internet-of-Things Using Regression Analysis

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**Abstract:** Internet of Things (IoT) is a popular social network in which devices are virtually connected for communicating and sharing information. This is applied greatly in business enterprises and government sectors for delivering the services to their customers, clients and citizens. But, the interaction is successful only based on the trust that each device has on another. Thus trust is very much essential for a social network. As Internet of Things have access over sensitive information, it urges to many threats that lead data management to risk. This issue is addressed by trust management that help to take decision about trustworthiness of requestor and provider before communication and sharing. Several trust-based systems are existing for different domain using Dynamic weight method, Fuzzy classification, Bayes inference and very few Regression analysis for IoT. The proposed algorithm is based on Logistic Regression, which provide strong statistical background to trust prediction. To make our stand strong on regression support to trust, we have compared the performance with equivalent sound Bayes analysis using Beta distribution. The performance is studied in simulated IoT setup with Quality of Service (QoS) and Social parameters for the nodes. The proposed model performs better in terms of various metrics. An IoT connects heterogeneous devices such as tags and sensor devices for sharing of information and avail different application services. The most salient features of IoT system is to design it with scalability, extendibility, compatibility and resiliency against attack. The existing works finds a way to integrate direct and indirect trust to converge quickly and estimate the bias due to attacks in addition to the above features.

**Keywords:** LRTrust; logistic regression; trust management; internet of things

### 1 Introduction

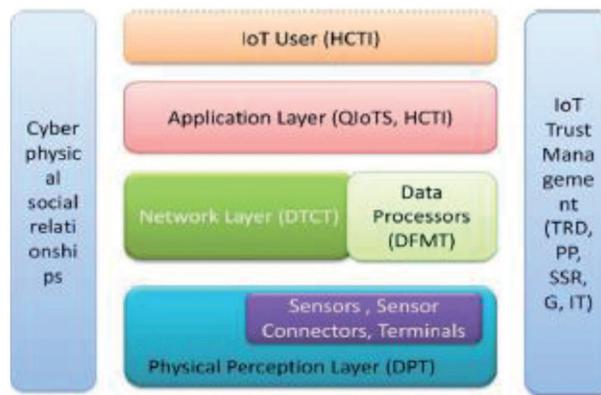
Internet of Things (IoT) is an emerging trend in network with attractive standards and infrastructure for sharing and communication in day to day life. IoT integrates heterogeneous physical objects into a network to share advanced applications between them. In future, this plays important role in social life. These data are



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mined for useful information for different applications. The future development of IoT is very promising as it is applicable in different areas such as health care smart home, surveillance, traffic control [1].

The IoT is prominent as it incorporates large count of heterogeneous objects in a standard network protocol with unique ID which is made available for end users at the edges. Its future extension is connecting the physical objects in cyberspace via Radio Frequency ID (RFID) and sensors [2,3]. The devices interact with physical world through Internet and sense the data from the operational environment [4]. So IoT is a paradigm with universal infrastructure for deploying data sensing devices and provide them resource usage. IoT is a three-layer structure as perception layer, network layer and application layer as shown in Fig. 1. The perception layer identifies physical environment and human social life; perceived data is processed and transformed by network layer and application layer offer intelligent services in prevalent manner. The layers are connected to one another across cyber, physical and social characteristics [5].



**Figure 1:** IoT-System model (Source: [6])

The IoT system is trustworthy, not just because of reliability between the layers but also regarding the privacy, security and trust properties of the layers and the whole system. Each layer's trust is very important. For example, even if the communicating network or application layer is trustable and the data from perception layer is not trustworthy, it greatly influences the quality. Some of the reasons like limited bandwidth, resource scarcity, mobile nodes and lack of scalability are some of the reasons that make IoT system more prone to attacks [7].

An IoT system requires a powerful security control as every element of it is liable to either internal or external threats. Consequently, the important is its privacy, which means that it is very important to know by whom and when the information is disclosed [8]. On preserving privacy, the system is trustworthy. One of the preceding aim of Internet of Things is to provide very personalized services to individuals in ubiquitous digital system that control devices in our day today life. This involvement of IoT will give way too many social changes and create many business opportunities [9]. More than expansion of the network, IoT gains more importance in terms of security. Each entity in IoT interact among themselves and send a request for the service of a provider. While in this interaction, a malicious device attack and abuse the resources, it is very important to ensure the trustworthiness of each provider in this universal environment [10].

The proposed work is a study on trust management for IoT consisting of service provider (trustee) and service requestor (trustor). The Trust is defined as belief or expectation of requestor on provider in terms of service quality fixing factors like integrity, availability etc. Trust is important measure of confidence and expectation in social communication as there is lack of monitoring the environment directly [11].

**Definition: Trust.** It is a qualitative or quantitative property of a trustee, evaluated by a trustor as a measurable belief, in a subjective or objective manner, for a given task, in a specific context, for a specific time period [12].

Trust is used to detect malicious node attack and its selfish nature in presence of several cryptographic attempts. According to the application and context, trust is evaluated in objective or subjective basis. This idea is applied in business via ecommerce where seller or buyer have no knowledge about each other [13]. In trust management model, more number of node collaborate with each other and share the ideas and recommend based on past history. The integration of past history from all heterogeneous node in different community in IoT is highly challengeable. Untrusted nodes intentionally send fake reports hence the system is vulnerable to attacks [14]. Trust is context specific and dynamic. Trust can be composed from indirect members in network. It is subjective indulging social factors in decision [15].

### *Social IoT and entity relationship*

IoT devices proliferate rapidly in supporting end-to-end services and application for which device authentication gains more importance. Apart from general characteristics such as resource limitation, memory constraint, mobility authentication and authorization are most important for security [16]. The Social Internet of Things (SIoT) connect people and devices in social network to navigate like human by devices. The objects were embodied as smart objects suitable for present communication mode. The IoT entities experience a pseudo-social behavior on interacting with social environment. Every object can establish social relationship with others forming SIoT network [17].

Objects can establish collocation relationship, co work relation and community relation like human with their neighbors. These relations are updated and human set the rules of the objects for using its services. The relation in SIoT may exist between object-object, human-human and human-object. It is important for IoT entity both human or device to know whether the others are trustable to provide service. The misbehaving may be human or owners of device again a human to false the other's reputation [18].

Trust is a measure to service oriented architecture (SOA)-IoT as its entities can be malicious for selfish purpose. If the trustworthy nodes are not identified, these malicious users may dominate the whole network. IoT support many applications like healthcare [19,20], product management, smart home application etc. It collects and share entity information on context base as the trust differ according to context i.e., separate trust value for each context. This context based evaluation increase the prediction accuracy.

The contributions of this paper are as follows:

1. We consider both QoS and Social factor for direct assessment and recommendation
2. We implemented Logistic Regression for Trust prediction and compared the performance with Bayes Inference with Beta distribution
3. Performance analysis on comparing the two models based on success rate, failure rate and bypassing rate. Performance of the model towards attack.

The rest of the paper is organized as, in Section 2, the survey of trust models and their methods and factors for evaluating trust is discussed. In Section 3, the basic dimension for designing Trust model is given. The Section 4 explains the basic model of Logistic Regression and its adaption to IoT. The Section 5 discusses the simulation detail and performance evaluation on comparing with Bayes-Beta model. The success rate and the resiliency towards attack is discussed. Last Section 6 conclude the work with pros and cons of the existing and proposed model with future ideas.

## 2 Related Works

As IoT involves heterogeneous type of devices with low or no storage or computational capacity, building an efficient trust management system is a challenge. Following are some of the existing research work admitted to bring out the pros and cons in constructing the trust model in various aspects. The author Kranz et al. [21] have worked to provide services on adding social and technical things both the human and technical entities of the IoT systems. The work of Atzori et al. [22] used social relationship and developed model called SIoT. It gives more importance to relationship rather than users.

Bao et al. [23] did QoS and Social factors and performed direct and indirect recommendation and also trust value is periodically updated. The system dynamically changes its member, behavior and interaction. But the system failed to attend scalability. Chen et al. [24] worked a model with two parameters, one is for weighting past history and direct assessment and another weights past history and recommendations. The system does not use any decay function and as it follows two way weighting method, it does not degrade trust. In the work of Roman et al. [25], it is cleared that the approaches used for traditional way is not suitable for IoT as many relationships exist and needs the system to be dynamic and scalable. Chen et al. [26] built a trust model using fuzzy approach. The system is designed with wireless sensors and take account QoS factors but does not consider social factors which have high impact on IoT trust.

Lize et al. [27] developed a distributed type of trust model in which both direct assessment and indirect recommendation is used. Social parameters such as honesty, cooperativeness, and community-interest are used. Two nodes rate each other on interaction. The performance is improved on adjusting the parameter according to the environment change. The work [28] used a credit or guarantor and reputation is used for social internet of things and measured the trustworthiness to identify the malicious node. Yu et al. [29] developed a model which used multi criteria system which includes network related parameters such as repetition rate, delay speed for packet forwarding. The model uses entropy theory and uses Dempster-Schafer theory for indirect assessment of node behavior. The performance was good in finding malicious node and need to attempt in lightweight trust management.

The paper of Hamdi et al. [30] designed an adaptive game based analytical model. The security mechanism can be activated and inactivated by using Markov game theory for uncertain variables. They simulated their model for epidemic virus spread wireless sensor networks. But failed to add the way to find any other node is comprised or not.

## 3 Design Dimensions of Trust Model

A good survey work of Cho et al. [31] clearly sketched the design steps for effective trust management system. The paper was supportive to consolidate the existing work in this area. The five design principles are trust composition, trust propagation, trust aggregation, trust update, and trust formation. These 5 principles are essential for a trust computation model. So far, the existing system followed various strategies under each principle. Due to space constraint, only relevant principles are explained in the following section.

### 3.1 Trust Composition

Trust composition refers to what components to consider in trust computation. Trust components include quality of service (QoS) trust and Social trust

### 3.2 Trust Propagation

Trust propagation refers to how to propagate trust evidence to peers. In general, there are two trust propagation schemes—that is, distributed and centralized. The trust score is forwarded to next neighbor peers so that it may be used for trust evaluation.

### **3.3 Trust Aggregation**

Trust aggregation refers to aggregating trust evidence collected through either self- observations or feedbacks from peers. Partial trust score at each instant can be done as direct assessment by trustor directly by self-interactions or done as indirect assessment from neighbors of both trustor and trustee. All the partial scores are aggregated to reach the final trust score. Some of the aggregation methods are a) Weighted Sum b) Bayesian Inference with Belief Discounting c) Regression Analysis d) Belief theory e) Subjective logic f) Certain logic g) Fuzzy logic.

### **3.4 Trust Update**

The trust score as time prolongs, it decays and not have that much impact on trust. Therefore, the trust value should be updated according to the new context. So trust is always calculated based on recent history records or experiences. Two schemes are followed namely event driven and time driven.

### **3.5 Trust Formation**

The overall trust is formed on aggregating already calculated direct and indirect value. The trust formation is of two type viz: a) Single trust b) Multi trust. In single trust, only one node whose interaction finalizes the trust level is considered. It may be direct trust. But multi trust is getting opinions from neighbors. So the devices in a relation repute the node for selection of Service Provider.

## **4 Materials and Methods**

The quality of our work is in building a trust inference model using Regression analysis and to predict the service behavior given context information as input. It is compared with widely used Bayesian model, which have strong statistical foundation.

### **4.1 Trust Management Protocol**

#### *Trust Management*

The designing of trust management challenges to handle heterogeneous devices, which are in huge count. The present system does not scale, as the entities are limited with capacity of storage and computation power. The another important challenge in the network is fully dynamic in nature that any number of node can enter or leave the network and this may fluctuate the degree of accuracy of the network [32]. The entities involved are mostly human handled devices. The social relationship is very important in IoT type of universal communicating network, so the relationship maintained between the owners are very important for the performance. The cyber-attack is unavoidable in such a big internet system, which clearly imposes the importance of building the trust system against the attack [33]. The protocol must be resilient against cyber-attacks in any hostile situation.

The protocol design of a node in our system has both QoS and Social properties. The propagation is in distributed manner as whenever a node wants a feedback it gets from the neighbor who might have experienced a provider earlier. Each node maintains a profile list consisting of service evidences that have experienced by them and may use as history for future decision. The report consists of parameter list and values, trust score of itself and about neighbors. This score is updated periodically and any trust is evaluated only with recent. The model has attempted to have a solution for the above said challenges and have studied the performance of the proposal on simulating a model environment. The hypothetical construction of the model is discussed in the following section.

The author of [34] have clearly surveyed and explained trust-computing models and classified based on data formation composition, updation, propagation and aggregation. Based on that notion, the proposed

system falls on both QoS and Social property in distributed manner, time driven updation with multi trust aggregation using Regression analysis.

#### **4.2 Overview of the System Approach**

1. Trust score is evaluated based on QoS criteria (usage cost, reliability and energy consumption) and social criteria (friendship, social contact and Community of Interest). The direct assessment of a requester on a provider is called as partial trust score, which leads to total trust score.
2. There is no central authority to control the process. Every node can be a requester and provider. Each of the node maintains evidences or past experience about other neighbors and when requested it is forwarded. The node also stores its own trust score.
3. The direct assessment and the originality of the recommender are weighted. In Bayesian model confidence level is checked whereas the intruders are detected as outliers.
4. Trust scores decay over time is done using decay function in Bayesian model. Similarly trust decay is time driven in regression analysis and the new trust level is reached for the new pattern at time  $t+1$ .
5. A trust aggregation function determines how partial trusts are aggregated to compute an overall trust score for a node. The aggregation function chosen depends on the collaboration context. Logistic regression method, which is a multinomial method, is adapted in the work for aggregation.
6. Trust updates (on partial trust scores) are time driven in given time.

The proposed system uses Logistic Regression model and study the performance against Bayesian with Beta distribution model.

#### **4.3 Bayesian Theory for Modelling Trust (Basic Model)**

A Bayesian model [32] uses Beta probability density function. It is a probabilistic model that relies on a Beta Function. Beta function Beta ( $\alpha, \beta$ ) is given as

$$f(p|\alpha, \beta) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} p^{\alpha-1} (1-p)^{\beta-1} \quad (1)$$

where  $p$  is the probability of the event occurrences, the value is in the range  $[0, 1]$ , and  $\beta > 0, \alpha > 0$ . When Bayesian model is applied for trust management process, direct observation and indirect recommendation is used. Direct observation is done when two users interact and indirect recommendation is the feedback about a user by third party.

Let  $s$  be successful transaction and  $f$  be failed transactions, then in a Bayesian model  $\alpha = s + 1$  and  $\beta = f + 1$ . For every node, any other node can be neighbor node and have interacted before. The experiences are given as feedback to a decision when requested. Let  $R_{xy}$  is the recommendation of node  $y$  by node  $x$ . The number of successful transaction between  $x$  and  $y$  is given as  $\alpha_{xy}$ . The number of failed transaction is  $\beta_{xy}$ . The recommendation evaluated by  $x$  on  $y$  is given as

$$R_{xy} = \text{Beta}(\alpha + 1, \beta + 1) \quad (2)$$

The indirect assessment  $R_{zy}$  by node  $z$  on node  $y$  is added to node  $x$ , with two parameters  $\alpha_{zy}$  and  $\beta_{zy}$ . The recommendation is denoted as  $R_{zy}$ . On aggregating this recommendation, the new recommendation is given as

$$R_{xy}^{new} = \text{Beta}(\alpha^{new}, \beta^{new}) \quad (3)$$

The expected trust value on node y based on x's assessment and z's assessment is given as

$$T_{xy} = E(R_{xy}^{new}) \quad (4)$$

$T_{xy}$  is calculated as expected value denoted as E by using probability distribution formula of Beta distribution. If the trust value is not satisfied, the node is distinguished as malicious node.

#### *Bayes Inference analysis with Beta distribution for IoT trust*

The detailed formulation of Bayesian model is not given in this paper as it is attempted by many researchers and can be referred from the Ref Wiki. The stepwise algorithm is as follows:

When node x computes the trust value of node y, the notation  $D_{xy}$  is used to represent the direct trust value node x has on node y. Take the interactions between node x and node y into account, the two parameters used to represent the observations are, respectively, the following:  $\alpha_{xy}$ , is the number of previous successful interactions with node y and  $\beta_{xy}$ , is the number of failed interactions with node y.  $D_{xy}$  is obtained by computing the expected value of the probability distribution function of the beta distribution as follows:

1. Node x compute the direct trust value on node y using no. of previous successful interactions s = 1 and no. of previous failed interactions f = 0.
2. Update the direct value of y periodically. Node x monitor node y at interval of time t and record it.
3. On introducing decay factor  $\lambda$ , update the trust.
4. Checking the credibility of direct trust using confidence level estimation.
5. Compare confidence level with threshold.
6. If confidence  $\geq$  threshold, the direct trust is credible and final trust = direct trust
7. Else, compute indirect trust from a recommender z.
8. Node x combine z's recommendation on its own record.
9. Choose important recommendation that support more to trust using entropy weighted method.
10. Compute entropy.
11. Compute entropy weight.
12. Summing all indirect recommendations with its weight give overall recommendations.
13. Final trust assessment of node y by node x on integration of direct and indirect trust using Bayes – Beta model for aggregation.

#### **4.4 Logistic Regression Analysis for Trust**

Regression analysis is applicable for interpolating insufficient sampling. Logistic regression is a regression method meant for binary resultant problem. The resultant of the classification is always two i.e., 1 or 0. In linear regression the output is a numeric value from which logistic differ. In this model linear variables of the input 'x' are integrated with Beta coefficients to predict the output 'y'. The predictions are transformed using logistic function. The Beta coefficients are trailed from training data. For this, Expectation-Maximum – likelihood (EM) is used.

Maximum-likelihood estimation is used by machine learning algorithm to study the distributions of the points. The coefficients that take the prediction result very close to 1 is best coefficients and the rest are predicted close to 0.

##### *4.4.1 Logistic Regression for Trust Management*

When the Logistic regression is applied for trust management, it studies the behavior pattern of the nodes in the given context. The statistical and theoretical base efficiently predicts the behavior of node in

dynamically changing environment. We name our model as LogisticRTrust. The model withstands recommendation attacks like ballot-stuffing and bad-mouthing attacks. This is made possible on using outliers to filter the mischievous node instead of filtering with threshold value. In our performance study, when we compared the model to Bayesian inference with Beta distribution, it outperforms the latter.

#### 4.4.2 Behaviour Pattern Assumptions

For the designing of the model, the following are the behavior assumptions taken. Every node in the IoT can be requestor and provider. Let the service requestor be SR and provider be SP. The heterogeneous SP are very dynamic in nature adapting itself to QoS and Social factors.

In a situation, when a SP is waiting for long time to leverage its service and have very less chance to be selected, it starts acting false to somehow make the SR to select it for profit. LogisticRTrust is multivariate and multinomial, and can accommodate different types of QoS and social factors [35].

#### Problem Definition

Let x, y and z are three nodes in IoT network. The node x in order to get the service of node y, it has to detect the trust level as score for the node y. The trust has to be evaluated on SP y by SR x having history of previous behaviour pattern. The node x have its direct observation  $o_{xy}^t$  on node y at time t. the observation reveal whether y is satisfactory (denoted as 1) or unsatisfactory (denoted as 0) in service quality. The QoS and Social factors considered at any time t are service usage cost, reliability, awareness, friendship, social connect and community of interest and denoted as a vector  $P^t = [p_c^t, p_r^t, p_e^t, p_f^t, p_s^t, p_{co}^t]^T$ . The trust that y provide satisfying service to the node x at time t is given as probability  $\theta_y^t$  for the parameter  $P^t$ . The node z is a recommender which have prior interacted experience with y and its observation along with parameter at t is maintained on itself in the form  $\{P^t, o_{zy}^t\}$ . i.e.,  $\{P^t, o_{zy}^t\} = \{[p_c^t, p_r^t, p_e^t, p_f^t, p_s^t, p_{co}^t]^T, o_{zy}^t\}$ . If SR z is satisfied with the service quality provided by SP y,  $o_{zy}^t = 1$ ; otherwise,  $o_{zy}^t = 0$ . For ease of implementation, the recorded values for all the parameters are taken as cosine similarity between the vectors of node z and node y. Cosine similarity is chosen because of its computational easy and less time.

The set of observations  $o_y = \{o_y^t, t = 1, \dots, T\}$  denote evidence gathered by SR x, including self observations and recommendations over  $[0, T]$  and  $P = \{P^t, t = 1, \dots, T\}$  denotes over  $[0, T]$ . LogisticRTrust learn the behavior pattern of SP y represented by a latent variable  $\beta_y$  between  $o_y$  and P, and predicting  $o_y^{T+1}$  given  $P^{T+1}$ , i.e.,  $E(o_y^{T+1}|P^{T+1})$ . This expectation lies between 0 and 1, representing the trust level of SP y at time  $T + 1$  from SR x's perspective.

#### 4.4.3 Logistic Regression Based Trust Method

LogisticRTrust use logistic regression [36] to study the relation between regress variables x and observations (binary) oy. LogisticRTrust is flexible to accommodate any number of environment-specific behavior pattern factor ( $p_x$ ) that is appropriate for an application. LogisticRTrust uses a linear predictor [36], given as

$$E[o_y^t|P^t, \beta_y] = \theta_y^t = \frac{1}{1 + e^{-(P^t)^T \beta_y}} \quad (5)$$

where E is logistic sigmoid function,

$\beta_y = [\beta_c, \beta_r, \beta_e, \beta_f, \beta_s, \beta_{co}]^T$  is a column vector of coefficients and  $\theta_y^t$  is in the range of  $[0, 1]$ . If  $(P^t)^T \beta_y \ll 0$ ,  $\theta_y^t$  is less than 0.5. which means the delivered QoS and Social parameters is unsatisfactory; otherwise, if  $(P^t)^T \beta_y \gg 0$ , the parameters is to be satisfactory. Following Eq. (5), we characterize the logged chance using logit function which is derived on taking logarithm of odds which is proportion of  $\theta_y^t$  (likelihood of presence) by  $1 - \theta_y^t$  (probability of absence). It is defined as logit ( $\theta_y^t$ ) as shown in Eq. (6)

Taking natural log on both sides we have

$$\ln\left(\frac{\theta_y^t}{1 - \theta_y^t}\right) = (P^t)^T \beta_y, \text{ or } \text{logit}(\theta_y^t) = (P^t)^T \beta_y \quad (6)$$

where the logit function, the probability that the service provided by SP y to SR x is satisfactory is equivalent to the probability that  $o_y^{t*}$  (unobserved random variable) is larger than zero, where

$$o_y^{t*} = \text{logit}(\theta_y^t) + \varepsilon_y \quad (7)$$

And  $\varepsilon_y$  is error given as  $\varepsilon_y \sim \text{logistic}(0, 1)$  with cumulative density function  $\frac{1}{1+e^{-t}}$   
 $t \in (-\infty, \infty)$

Thus on this basis, the relation between  $o_y^t$  and  $o_y^{t*}$  is

$$o_y^t = \begin{cases} 1 & \text{if } o_y^{t*} > 0 \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

Here, the observation history  $\{P, o_y\}$  is a collection of self-observations of SR x and recommendations provided by recommenders  $z \neq x$  upon encountering SP y in IoT.

#### 4.4.4 Filtering Recommendation Attacks as Outliers

LogisticRTrust absorbs malicious recommenders who on purpose hide the actual observations. For example if the recommender  $z$  itself is malicious node then it will twist its recommendation as  $\{P^t, 1 - o_{zy}^t\}$  to perform a recommendation attack. This node is called as outliers, which distract the inferred  $\beta_y$  away from the true behavior. If we follow the logistic distribution with an error term, the solution accuracy is very sensitive to outlier's side and therefore recommender attacks greatly influence the prediction accuracy. In order to tolerate outliers without affecting the prediction accuracy, we go for white noise in t-distribution.

Generally, the statistical inference model based on normal distribution either uni or multivariate is known to be vulnerable to outliers. Also, the statistical model relies on t-distribution when the sample size is very small, variance is unknown and standard error is too small to decide the uncertainty. Graphically, the t-distribution results in heavier tails to be robust to outliers by increasing the probability of faraway samples from the mean. The LogisticRTrust model is advantageous to tolerate the outlier recommendations using t-distribution, so that it is resilient to recommendation attacks.

White noise is discrete signal in discrete time with zero mean and finite variance for the samples of uncorrelated random variables. A t-distribution is probability distribution with heavier tails and it tends to give values far from its mean on giving more chance to extreme values. The t-distribution is more vigorous against outliers and protects  $\beta_y$ . The general t-value formula for n samples with expected  $\mu$  is given as

$$t = \frac{\bar{x} - \mu}{s/\sqrt{n}}, \text{ where } \bar{x} \text{ is sample mean and } s \text{ is sample variance}$$

We replace the latent error in logistic distribution in Eq. (7) with white noise t-distribution, which have means as 0 and the degree of freedom ( $v$ ) which refers to the maximum number of logically independent varying values in the data sample. For example, the number of distinct neighbors from whom the recommendation is taken.

Replacing  $\varepsilon_y$  by a standard t-distribution random variable and the product of parameter and its coefficient  $(P^t)^T \beta_y$  is represented as  $q_y^t$ , also the optimal degree of freedom ( $v_0$ ) is for tolerating outliers, we have  $o_y^t \sim t(q_y^t, 1, v_0)$ . On applying Expectation Maximization (EM) algorithm along with iterative re-

weighted least squares,  $\beta_y$  is estimated. Then t-distribution is approximated using infinite sum of normal distribution with different variance.

Therefore weight  $\omega^t$  for each  $o_y^{t*}$ ,  $x = 1, \dots, I$ :

$$o_y^{t*} | (\omega^t, \beta_y) \sim \mathcal{N}\left(q_y^t, \frac{1}{\omega^t}\right) \quad (9)$$

$$\omega^t | \beta_y \sim \Gamma(v_0/2, v_0/2) \quad (10)$$

The expected weight of  $\omega^t$ ,  $t = 1, \dots, T$  with current  $\beta_y$  is computed in the E step of EM.

In the M-step of EM, compute a new  $\beta_y$  that achieves the maximum likelihood. The basic steps of EM algorithm is given as

- i) Given an initial set of observed values as set of starting parameters.
- ii) **Expectation** (E – step): Using the observed data of the dataset, variables are updated on estimating expected value or missing data.
- iii) **Maximization** (M – step): the data after the expectation (E) step is used in updation of hypothesis i.e., maximum likelihood.
- iv) Repeat E and M step until convergence to expected output.

Finally, we compute

$$E[o_y^{T+1} | P^{T+1}, \beta_y] \quad (11)$$

#### 4.4.5 Algorithm in Steps (LogisticRTrust)

- i. Input P (recorded behavior pattern at time T)

Input  $o_y$  (service evidence recorded at j)

Input  $v_0$  (degree of freedom is 4)

Input  $P^{T+1}$  (behavior pattern at T+1, at which trust is predicted)

- ii. Initialize iteration index  $k = 0$

Initialize regression coefficient vector  $\hat{\beta}_y^{(k)} \leftarrow 1$

Expectation Maximization Algorithm to infer new coefficient  $\hat{\beta}_y$

- iii. Repeat Step 3 for  $t = 1$  to  $T$

- a) Move  $(P^t)^T \hat{\beta}_y^{(k)}$  to  $q^t$

- b) Compute conditional expectation weight

$$\hat{\omega}^t \leftarrow \frac{o_y^t - (2o_y^t - 1)F_{v_0+2}(-(1 + 2/v_0)^{1/2}q^t)}{o_y^t - (2o_y^t - 1)F_{v_0}(-q^t)}$$

Where  $Fv(x)$  is cumulative density for random variable x

- c) Compute latent variable

$$\hat{o}_y^{t*} \leftarrow q^t + \frac{(2o_y^t - 1)f_{v_0}(q^t)}{o_y^t - (2q_y^t - 1)F_{v_0+2}(-(1 + 2/v_0)^{1/2}q^t)}$$

- d) Where  $f_v(x)$  is probability density function

iv. Compute maximum likelihood

$$L_0 \leftarrow \sum_{t=1}^T \hat{\omega}^t P^t P^{tT} \quad \text{and} \quad L_1 \leftarrow \sum_{t=1}^T \hat{\omega}^t P^t \hat{o}_y^{t*}$$

v. Increment k = k+1

vi. Renew the estimate  $\hat{\beta}_y^{(k)}$  by  $\hat{\beta}_y^{(k)} \leftarrow L_0^{-1} L_1$

vii. Repeat Step 3–6 until converges

viii. Output trust by  $E(o_y^{T+1}|P^{T+1}, \hat{\beta}_y) \leftarrow \frac{1}{1+\exp(-(P^{T+1})^T \hat{\beta}_y^{(k)})}$

In the above LogisticRTrust algorithm, the initial behaviour pattern from which trust level is studied and degree of freedom decided is given as input. The degree of freedom is number of independent observations allowed in sample set to participate in estimation part. When degree of freedom decreases, t-distribution attains thicker tail, which show more uncertainty when sample size is small. When degree of freedom increases, the t-distribution tail is thinner but area near center increases so that more sample points are taken for estimation, which lead to accurate trust prediction performance even when the sample size is small. Therefore, the degree of freedom is taken as 4 to account reasonable number of samples required for prediction.

The pattern for which the trust of SP is to be predicted is given as input. The step1 is given input. Step 2 initialize k for number of iteration and initial column vector  $\hat{\beta}_y$ , is all-one column vector. Step 3 and 4 is E-step, taking current  $\hat{\beta}_y$ , the conditional expected weight  $\hat{\omega}^t$  and latent observed value  $\hat{o}_y^{t*}$  is evaluated. The conditional expected weight  $\hat{\omega}^t$  uses  $F_u(x)$  is cumulative density for random variable x and latent variable uses probability density function  $f_u(x)$  for estimation. The  $\hat{\omega}^t$  reduce the impact of data with high variance to easily identify outliers. The likelihood function measures the goodness fit of the model for values of unknown parameter and stability of the fitness. The partial likelihood which is natural log of likelihood is used for convenience to estimate the maximum likelihood. The Step 4 evaluate partial likelihood  $L_0$  and  $L_1$  which is used to estimate the maximum likelihood in Step 6. Repeat until converges. The inference of output at step 8 predicts the trust level of service provider SP y at time T+1 for the given parameter pattern which are operational and environment factors of IoT entities.

#### 4.4.6 Trustworthiness of Node Based on Prediction

Trust on each other IoT entities (nodes) is essential for nodes in uncertain and dynamic network such as IoT. The gathered assessment is propagated as recommendations to other requested nodes. With the help of recommendations, SR build trustworthiness, confidence and expectations on a SP accounting on several characters such as QoS factors and social factors. Every node will have the history of interaction and trust assessment of already serviced nodes. Trust predictions can be done to reason the future behavior tendency of a node a for particular instant. Trust is subjective and non-symmetric. Each entity of IoT takes decision on SP based on the evidences collected from direct observations and recommendations. Recent interaction history about the nodes is captured at different operational condition for latest information.

In the proposed work,  $o_{zy}^t$  are evidences on SPy observed at time t intervals for required condition. It is based on recommendation done by node z. The SP<sub>y</sub> is denoted as 1 if trusted by z otherwise set to 0. The algorithm learn the pattern represented by latent variable. On predicting  $o_y^{T+1}$  for given  $P^{T+1}$  for time t = T+1, the conditional expectation is valued between 0 and 1 to represent the trust level of SP<sub>y</sub>. When SR is satisfied with SP based on recommendation by its neighbors it selects the SP for its service. The untrusted SP's are rejected for further nomination.

## 5 Performance Evaluation

The following are the metrics used to evaluate the efficiency of the model.

### 5.1 Performance Metrics

*Success Rate ( $S_{xy}$ ):*

The ratio of the number of trustful services received from SP y (i.e.,  $|S_{xy}^+|$ ) to the total number both trusted and untrusted services received by SR x (i.e.,  $|S_{xy}^+| + |S_{xy}^-|$ ) as a whole. It provides the decision accuracy. Therefore, the success rate  $S_{x,y}$  is given as:

$$S_{x,y} = \frac{|S_{xy}^+|}{|S_{xy}^+| + |S_{xy}^-|} \quad (12)$$

*Failure Rate: ( $F_{x,y}$ ):*

It is opposite to the  $S_{xy}$ . The failure rate can be considered as the false negative rate i.e., a bad SP is mistrusted as a good SP.

$$F_{x,y} = \frac{|S_{xy}^-|}{|S_{xy}^+| + |S_{xy}^-|} \quad (13)$$

*Bypassing Rate ( $B_{x,y}$ )*

It is the rate of missing a satisfactory service.

$$B_{x,y} = \frac{M_{x,y}^+}{M_{x,y}^*} \quad (14)$$

where  $M_{x,y}^*$  is number of services of y not selected by x and  $M_{x,y}^+$  is number of satisfactory service among  $M_{x,y}^*$  that SP would have given if selected. The bypassing rate can be considered as the false positive rate because a good SP is missed as a bad SP

A confusion matrix is a simple interpretation to measure the hazard of misclassification, which reflects in the performance of the model. In a trust model the selection of malicious node as service provider will have adverse effect on trustworthiness of total network. False negative and false positive factors are important measures that lead to misclassification of good and bad nodes. Minimizing False positive and False negative rate leads to ideal performance of the trust system [36]. In the proposed evaluation step, Failure rate: ( $F_{x,y}$ ) is False negative rate used to measure the mistrust of a bad SP as good one and Bypassing rate ( $B_{x,y}$ ) is False negative rate to measure a missing a satisfactory SP when he performs good. When the trust level of the service provider is satisfactory, the service requestor can decide to interact.

### 5.2 Environmental Setup

We conducted python simulations to evaluate LogisticRTrust model. The simulation setup is done with 100 nodes with 30% with IoT devices with limited storage and capacity assumptions in  $10\text{ m} \times 10\text{ m}$  with 6 different COI. With on a total of 20% of malicious node and the time slot for 1 day with 2 h of intervals.

### 5.3 Experimental Setup

Let C be the set of all nodes in IoT context space with Users U and devices D = {D<sub>1</sub>, D<sub>2</sub>...D<sub>n</sub>} with limited capacity called as IoT devices Both users and devices are called nodes.. Every node  $\epsilon$  C, maintains a profile list and friends list. The friends list consists of neighbors with friendship relation. The profile maintained at each node is in the form of tuple like T(N<sub>x</sub>) = {T<sub>xy</sub>, P [], Tx, time} where

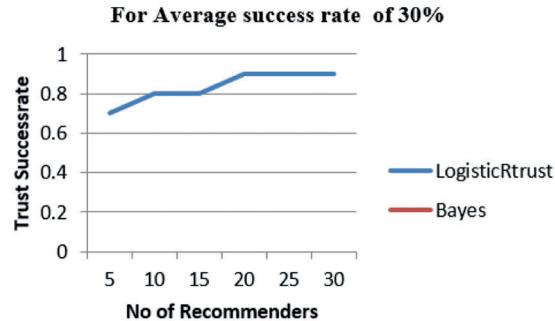
$T_{xy}$  = Trust assessment of node x on y, P [] = QoS and Social parameters,  $T_x$  = Its own trust score at a time t, Time is updation time interval. From the node for a node as provider 204 interaction history is recorded. The parameter pattern of QoS and Social parameter of 100 records are randomly generated for the experiment. The degree of freedom is 4. The recommenders are categorized as honest type, neutral type and dishonest type.

Our IoT trust management protocol is distributed. The five design steps of designing trust management Trust parameter formation, composition, propagation, updation and aggregation to final trust are implemented both in Bayesian trust model and Regression analysis model to study the performance. Trust is predicted in a situation where a service requestor SR x puts request to neighbors. a service provider SP y claims that it can provide. SR x wants to know the trustworthiness of SP y. Based on the prediction of trust score using LogisticRTrust algorithm SR x decides on SP y. We framed the decision is in such a way that if the trust level is less than  $R_{succ} = 0.5$ , SP y is rejected else SP y is selected. Two experiments one below the success rate and another above the success rate is considered. i.e., 0.3 (30%) and 0.6 (60%).

#### 5.4 Comparative Analysis on Trust Accuracy When Average Success Rate is 30% and 60%

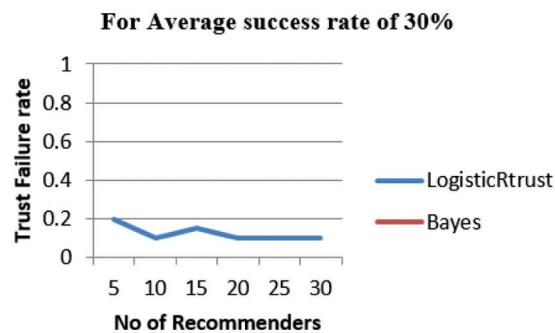
The following figures compares the service prediction accuracy between LogisticRTrust and Beta reputation when there is 30% successful recommenders.

From Fig. 2, LogisticRTrust shows trust score above the threshold 0.5 fixed in this experiment setup whereas Bayes does not appear as it is below 0.5 which means tested node are not recommended. This is because Bayes-beta assumes the mean trust using number of positive and negative observations. Therefore, over estimation or under estimation occurs based on the mean value and performs poorly.



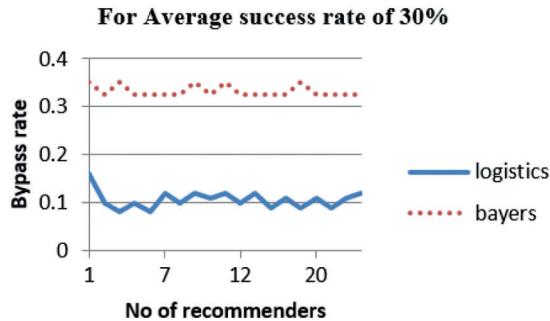
**Figure 2:** Success rate of trust for 30% of successful recommenders

From Fig. 3, LogisticRTrust shows very low Failure score below the 0.5 but there is no value for Bayes which means it falls around 0.3(30%) which is not considered.



**Figure 3:** Failure rate of trust for 30% of successful recommender

From Fig. 4, while 30% of average success rate, the LogisticRTrust model show low bypassing rate (lower false positive rate) whereas Beta is closer to 0.3. Bayes-Beta reputation is not sensitive to the number of recommenders. This is because the trust value obtained by Bayes-Beta reputation is close to the SP's average success rate (30%) and is always below 0.5 consideration level.



**Figure 4:** Bypass rate of trust for 30% of successful recommender

LogisticRTrust consistently predicts a high service success rate over and above  $R_{succ}$ , while Beta reputation produces a success rate that ranges always below nearer to  $R_{succ}$ . This reason is Beta reputation considers only the numbers of positive and negative observations. We also note that for Beta reputation, the values for the success rate and failure rate are not available when  $R_{succ} = 30\%$ . This is because when  $R_{succ} = 30\%$ , the trust value of  $SP_y$  predicted by Beta reputation is also around 0.3. Since it is less than 0.5, a SR following the SP selection rule will never select  $SP_y$  for service. When this situation avoids failed service from  $SP_y$ , some of the good services of  $y$  is also missed. The same result of 30% is attained for  $R_{succ} = 60\%$  showing the behavior of the model is consistent effect for all cases. Due space constraint the successful rate, failure rate and bypassing rate of the 60% result is not included in the paper. Some of the sample result of values that reflect efficient classification obtained are (0, 0.1, 0.2), (0.1, 0.1, 0.2) for low hostility, (0.1, 0.3, 0.4) (0.5, 0.2, 0.1) for medium hostility and (1.0, 0.5, 0.2), (0.1, 0.6, 0.1) for high hostility.

Overall, LogisticRTrust produces a higher and more consistent service prediction accuracy than Beta reputation. This is because Beta reputation assumes a static hidden mean trust value considering only the numbers of positive and negative observations. It performs poorly due to overestimating or underestimating the trust by using the mean value.

### 5.5 Comparative Analysis on Resilience Against Attacks

The second set of experiment focuses on the resilience against malicious recommendation attacks. Based on the relationship of the recommender to trustor and trustee, the hostile situation is considered as low hostile, medium hostile and high hostile situation. During the requisition for a feedback about a trustee, the recommender can be loyal or malicious. So for the study, its behavior is taken as honest friend, neutral and dishonest or selfish. The attack made by the recommender are trustor based or trustee based. The important bad mouthing attack and bad stuffing attack are dealt here.

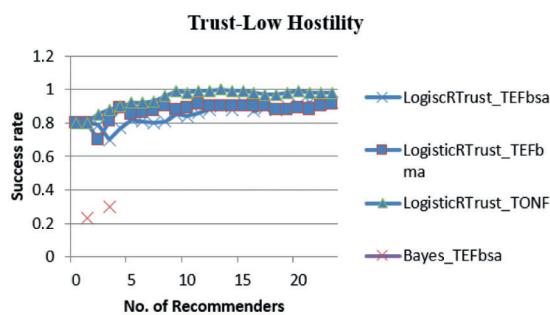
- a) Recommender-Trustor– Friend/Not Friend: in this case the recommender give good opinion as the trustor is a friend. However, when the trustor is not friend in order to divert the decision, it hides the truth about the trustee giving bad opinion.
- b) Recommender-Trustee-Friend (BSA): In this case, the recommender being a good friend to the trustee, even if he is not trustable, gives more reputation about trustee friend. This is called ballot-stuffing attack leading to select untrusted provider.

- c) Recommender-Trustee-Not Friend (BMA): In this case, when the requestor or trustor ask for feedback, as the trustee is not friend in order to ruin his selection, bad opinions are given to the trustor so even if he is a satisfied node to give the service, he may not be selected.

A sample of probability value for the recommender being friend, neutral and dishonest is taken for the study. The values for low, medium and high hostile situation is given below.

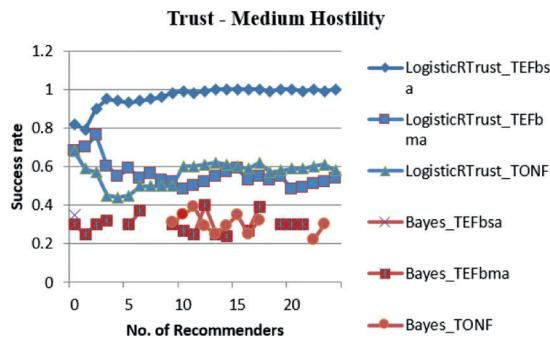
The trust value for the above values for three cases with friend relation is given in the following figures. The success rate is plotted against the recommenders and plot is done for both Bayes- beta and proposed LogisticRTrust model.

From Fig. 5, it infers that the behavior of both Logistic and Bayes perform as there is no attack and so the Logistic curves are nearer to maximum trust mark (i.e., 0.5)



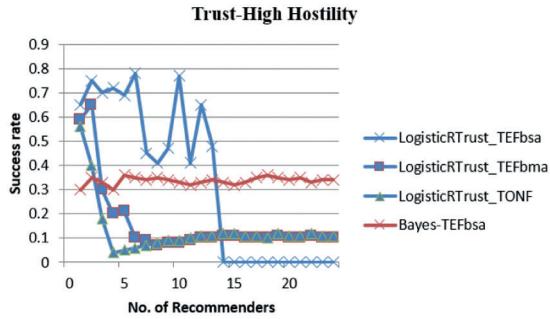
**Figure 5:** Success rate of LogisticRTrust and Bayes for low hostility

From Fig. 6, it implies that both Logistic and Bayes curves are visible. However, the values of Bayes – Beta model lies below the allowed Trust value. As it is below 0.5, the Service Requestor will not decide to select those nodes.



**Figure 6:** Success rate of LogisticRTrust and Bayes for medium hostility

From Fig. 7, in high hostility situation, Logistic performs better but still most of the points are very low which means only if the model clearly filters out the recommendations under bad mouth attack and TONF they are resilient to the attack. It is seen that it is deviated more from the actual behavior.



**Figure 7:** Success rate of LogisticRTrust and Bayes for high hostility

Tab. 1 shows some sample of values we observed for low, medium and high hostile condition respectively. From the graph, it is observed, that the proposed LogisticRTrust perform well than Bayes for the above hostility situation and mitigate against the malicious node. Thus, resiliency to bad mouthing and ballot stuffing attack the proposed model is effective.

**Table 1:** Attack probability of friend, neutral and dishonest relation in low, medium and hostile situation

Hostility → Relation ↓	Low	Medium	High
To trustor (NotFriend) (TONF)	0	0.5	1.0
To trustee (Friend) (TEFBsa)	0	0.5	1.0
To trustee (Not Friend) (TENFBma)	0	0.5	1.0

Bayes with Beta model responds against the attack by dynamic weighting method where more weight is added to important recommender. Again, it depends on the trustor's ability to judge the recommender. Whereas, LogisticRTrust rely on statistical detection of outliers so that actual trust evaluation is not polluted. In high hostility situation, the underperformance of Logistic model can overcome by taking recommendations from more number of true friends. The performance may perform little worse when the node of different community of interest is in recommendation list. These are some situations under which regression model need to be analysed more. Regarding Computational feasibility, when LogisticRTrust algorithm is run the EM algorithm for inferring new predictions only for periodical interval shows reasonable runtime and storage.

## 6 Conclusions

The proposed LogisticRTrust model based on regression analysis for trust management in IoT showed an enhanced performance in trust prediction and in mitigating against trust based attacks. We considered Bayes analysis as it has strong statistical support for trust management. Existence of very few works using Regression Analysis in Trust management motivated to study the performance of Logistic Regression method in judging the honesty of nodes in network. Regression method is preferred as it can admit multiple variants, which is very essential condition of IoT environment. Moreover, the algorithm periodically records the behavior pattern of the nodes in social network which changes dynamically and can enter and leave a network at any time.

From the study, LogisticRTrust outperforms Bayes-Beta with high service success rate, failure and bypass rate in both the cases of above and below average success rate. The performance is due to the behavioral pattern study of the nodes based on social relationships viz. friendship, cooperativeness and Community of Interest, which influence trust highly. The reason for less performance of Bayes when compared to LogisticRTrust is of considering only negative and positive feedback from recommenders, which lead them to judge a bad node with good behavior, or sometimes misses the service of a good provider as bad one.

The experimental evaluation also indicates that at two situations where the LogisticRTrust algorithm underperforms. It can perform well in high hostile situation only when it is able to filter recommendations of strangers and take more recommendations from close friends. The future work carries the analysis of Regression model for centralized system, when the data are very sparse in case where difficult to classify the outliers and to study the impact of various social relationship on total trust when regression analysis is used to predict the trust.

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