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Owners' Collaboration In Running An IoT: An Evidential Model

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***Abstract**:*
There are many owners in an IoT. Every owner sees the same IoT through his own smart devices that are part of the IoT. An owner's operational data is generated at the edge layer but is immediately transmitted to the cloud where it resides quasi-permanently. An owner in the IoT computing environment, however, can always process his own data in the cloud and generate the decision support he needs to manage his part of the IoT. Unfortunately, the great loads of operational data add too much confusion and a great deal of uncertainty. The presence of great amounts of ambiguities and inconsistencies make it impossible to apply Bayesian reasoning in modeling an owner's decision process. This study proposes a decision support mechanism where weuse cloud data to construct belief structures on owner's decision parameters which are used in managing the owner's part of the IoT environment.
We provide a numerical example to demonstrate the working of the proposed model.

***Keywords**: IoT, Cloud computing, Dempster and Shafer Theory, Belief structure.*

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I. Introduction

IoT have been around for some time but their development have been slow due to the slow development of the communication technology needed to allow for cellular, satellite, and LAN connectivity solutions and specific protocols for sharing data among IoT devices [1][3]. Lately, however, we started seeing an intensive adoption of the IoT technology in various domains, as in medical, and manufacturing applications [6]. The adoption of IoT has made possible for companies to improve their managerial decisions and enhance their performance, including a great competitive advantage [2][4].

The IoT is often configured to be managed by different owners who own parts of the IoT made of the smart devices they added to it [6]. While the involvement of major owners seems to be a great managerial approach to secure the business continuity of the IoT, the IoT performance may depend on how well are configured its owners' actions. It will be very advantageous to the IoT if we can standardize owners actions to minimize any conflicts that can negatively affect the working of the IoT.

We are proposing a managerial control approach where owners rely on the insights they get from applying a standard data process on their operational data that is continuously accumulated in the cloud. This approach will 1) extract a random subset of data on the owner's decision parameters, 2) construct owner's belief structures of the data subset, and 3) produce insights that are interpreted by the owners and upon them.

II. A brief review of DST evidential theory

Evidential calculus is adopted in this study by using belief functions that is part of Dempster–Shafer theory (DST). This theory started with Dempster in 1968 as statistical inference and has been later formalized by Shafer, in 1976, as a theory of evidence [7] [8]. Smets expanded this theory by adding the Transferable Belief Model which is now widely applied in diverse AI applications in many domains[8]. In general, it is an extension of Bayesian reasoning that uses a mathematical framework for uncertainty management. We need to adopt the same frame of discernment in studying a finite set of mutually exclusive outcomes about their decision domain, which will allow us of combining evidence from different sources and produces a belief function, that takes into account all available evidence. Beyond Bayesian reasoning the DST has a superior expressive power when information is incomplete or data is not of good quality.

In the absence of a probability distribution, we can use DST to model a belief structure for a decision domain with a frame of discernment **Ω**, and assuming mutually exclusive subsets of the frame of discernment **Ω**, we can build a basic probability assignment m used to allocate a belief value in [0, 1] for every hypothesis defined by the subsets in the frame of the discernment, as follows:

$$m: 2^{\Omega} \rightarrow [0, 1];$$
$$m(\emptyset)=0;\ m(A)\geq 0 \text{ for any A in } 2^{\Omega};$$
$$\sum_{A \subseteq \Omega} m(A) = 1.$$

DST also provides an effective mechanism to combine evidence when multiple independent sources are considered. Dempster's rule of combination of evidence consists of a mapping that considers multiple sources and produces a composite source that represents the combined impact of sources as one combined measure of belief. If we have two independent sources of evidence defined on the same frame of discernment **Ω** and with basic probability assignments m_1 and m_2, we use Dempster's rule to combine evidence as follows:

$$m_{\Omega}(A) = \sum_{B \cap C=A} m_1(B)m_2(C)/(1-K); \text{ for } A\neq\emptyset$$
$$\text{Where } K= \sum_{B \cap C=\emptyset} m_1(B)m_2(C) \text{ and } m_{\Omega}(\emptyset)=0$$

The quantity K represents the basic probability mass associated with the conflict between m_1 and m_2. It is computed as the sum of the products of the basic probability masses of all the disjoint sets from the tow sources of evidence.

III. Presentation of the model

Lets let D be the set of data subsets D_k, k=1,|K| extracted from the cloud that concern owners decision parameters. Even though these data are originally generated at the IoT devices, we only process them when they are accumulated in Cloud storages. Figure 1 depicts the data accumulation process in an IoT environment.

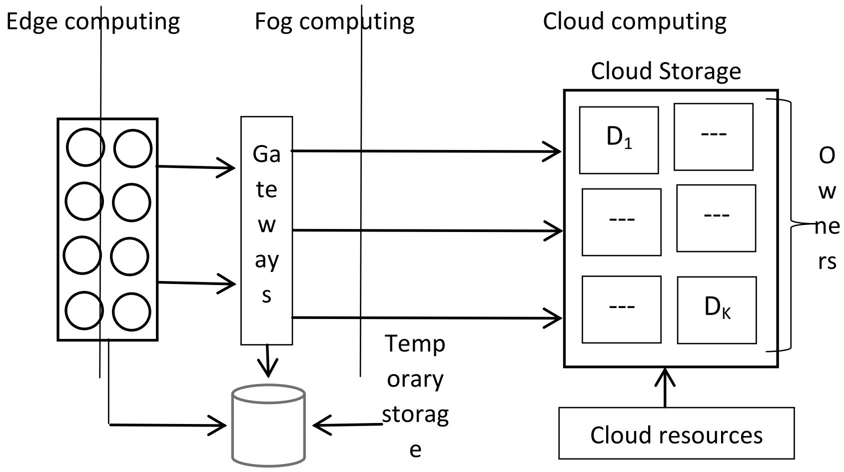

Figure 1: K owners in charge of their parts of the IoT

Owners own a group of devices in the IoT environment and reserve their own decision parameters through which they see IoT performance. An owner i is concerned with M_i decision parameters, also called attributes $\{A_{im}\}$, m=1,M_i when data is processed. These attributes constitute a data subset D_i with M_i attributes and N_i tuples. This data subset will be extracted and processed to produce owner i's belief structure m_i. This belief structure is defined as follows:

$$m_i: 2^{E_i} \rightarrow [0\ 1]$$
$$E_i = 2^{A_{i1}} \times \ldots \times 2^{A_{iM_i}}$$
$$m_i(x) = |S_{D_i}(x)| / |S_{D_i}(E_i)|$$
$$\text{where } S_{D_i}(E_i) = \{\{y \varepsilon D \text{ such that } y \Delta x\}, x \varepsilon E_i\}$$

The feasibility of Cloud data can only be justified in terms of the business value generated to owners as a result of actioning decision support information produced by big data analytics. Also, Cloud data itself is not of any value unless decision support can be created. That is, we only extract data from Cloud data to generate mathematically-sound decision support information.

As shown in Figure 2, there may be conflicts among IoT owners when they manage their parts of the IoT. While these conflicts are beyond the scope of this study, they can be mitigated when owners adopt the same data process that produces the insights that lot owners use in their decision-making process. Insights are obtained from the interpretations of various belief structures created for owners.

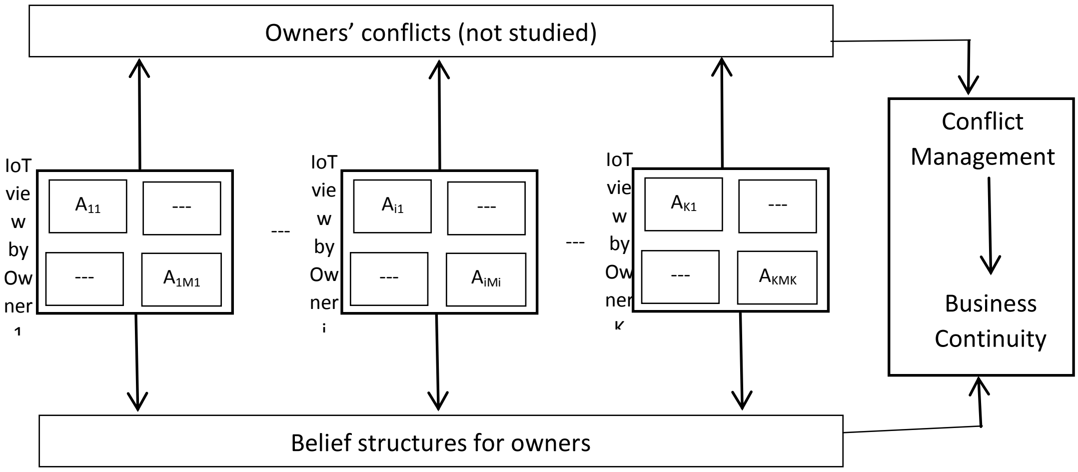

Figure 2: K owners collaborate in managing the IoT by following the same data process

Owner i views the IoT through the devices he owns and manages, and all through M_i parameters $\{A_{i1}, \ldots, A_{iMi}\}$. While there is an abundance of operational data that is created at the edge layer and then transmitted to the cloud where its resides permanently, only those data that related to the owner's parameters are extracted for analysis. Let us assume that the owner's data on $\{A_{i1}, \ldots, A_{iMi}\}$ are stored in D_i in a relational manner. The owner's evaluation and interventional management activities are performed based of the insights produced by processing the subset D_i. However, in the absence of a statistically-sound Bayesian measure, we use a belief structure as in DST.

That is, owner i is only concerned with the operational data originating from his own devices and some relevant devices of interest, from which we extract N_i data elements for M_i attributes, stored in the data subset D_i. In order to construct a belief structure on D_i, we will study all possible events associated with Di. These events are hypertuples made of the product of subsets in Ω_{im}, m=1,M_i. Those events with null masses are not feasible and are not considered in constructing the belief structure. This data process, depicted in Figure 3, is hence only concerned with those feasible hypertuples with positive masses. In order to do so, as in [5], let Δ be a partial order relation between Di and $F_i=2^{\Omega i1} \times \ldots \times 2^{\Omega Mi}$, defined as follows:

'If $x \in D_i$ and $y \in F_i=2^{\Omega i1} \times \ldots \times 2^{\Omega Mi}$,
$x \Delta y$ if and only if $x \subseteq y$'

The inclusion in the partial order relation Δ defines the amount of support x provides to y, or alternatively, the extent to which x is compatible with y, or the extent to which x is favorable to y.

Let us define the evidence support, denoted by $S_{Di}(y)$ where y belongs to $2^{\Omega i1} \times \ldots \times 2^{\Omega Mi}$, as the set of x's in D_i such that $x \Delta y$. That is,

$$S_{Di}(y) = \{x \varepsilon D_i, \text{ such that } x \Delta y\}.$$

The basic belief assignment associated with the belief structure is computed as follows:

$m_{Di}: F_i \rightarrow [0\ 1]$
If $e \in F_i$, $m_{Di}(e) = |S_{Di}(e)| / |S_{Di}(F_i)|$
where $S_{Di}(F_i) = \sum_{e \varepsilon Fi} |S_{Di}(e)|$

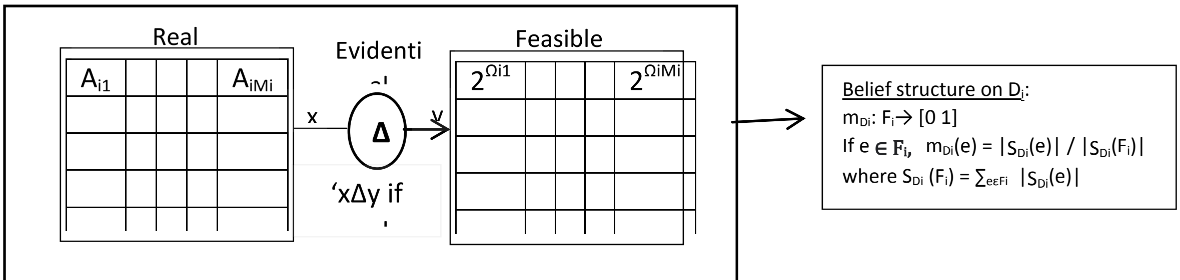

Figure 3: Process for constructing the

IV. Demonstration of the model

Assume an owner with several smart devices added to a specific IoT environment and assume that the owner selects two parameters A and B to be the main relevant decision parameters that he uses in managing part of the IoT environment. Let Ω_1={u, f} and Ω_2={1, 2, 3} de the domains for respectively A and B. Let us also assume that the following data set D is extracted from the cloud to generate decision support.

In this example, we can see that the data considered gave more support to events defined by the hypertuples e7, e8, e11, and e14. These are insights that the owner needs to interpret them and make the most appropriate decisions.

In the real world, an owner will have groups of decision parameters for which he extracts sufficient data on which belief structures are constructed using Dempster and Shafer theory. The evaluation of the belief structures will produce very useful insights that will be interpreted and acted upon them.

If all owners adopt the same approach we proposed above, all owners will understand better the behavior of their part of the IoT. This way, they can have a sound evaluation of the belief structures they produce on their data, and a sound interpretation of resulting insights upon which decisions are made. By performing their roles as mangers of their parts of their IoT, owners can assure the business continuity of the IoT as initially configured.

V. Conclusion

Owners of an IoT all participate in running the IoT by running their part of the IoT that consists of their own smart devices. They collect a great deal of operational data that describes the operations of their part of the IoT. The article proposed an evidential model capable of constructing owners' belief structures for the decision parameters they use to manage their part of the IoT. Useful insights can be produced based of the belied structures and then interpreted and acted upon them.

This research may be extended by evaluating the conflicts that can occur when owners's decisions, even though using a statisticall sound evidential model, enter into unexpected contradiction. The extension can estimate possible conflicts and study their impact of the business continuity of the IoT.

This article provided a numerical example that demonstrates the working of the proposed model.

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