A Trust Model for Uncertain Interactions in Ubiquitous Environments[1]

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The notion of trust has played an important role in ubiquitous computing (*ubicomp*). It supports uncertain interactions and collaborations between mobile entities. Most of previous work on trust did not attach enough importance to uncertainty. Besides, these works draw a general picture without any detailed computational model. In this paper, we present a trust model based on the vectors of trust values including *peer recommendation, confidence, history of past interaction,* and *time-based evaluation*.

Whenever two principals want to interact, they should be able to evaluate the amount of trust on each other using some evaluation metric. This metric should include the recommendations of other principals that had past experiences with these principals; the more the experiences, the higher the weight of these recommendations. Also, the interacting principals' past experiences with each other should obviously have a say in this evaluation. First, we define some basic notions:

Definition 1 The *trust vector* of principal Q_i is defined as:

$$\overrightarrow{Q_i} = \left(t_{Q_i,Q_1}, t_{Q_i,Q_2}, \ldots, t_{Q_i,Q_{i-1}}, t_{Q_i,Q_{i+1}}, \ldots, t_{Q_i,Q_n}\right)$$

where *trust value* of Q_i on Q_k: $t_{Q_i,Q_k} = NULL$ if they have NOT interacted before ($i \neq k$).

Definition 2 The *peer set* of a principal Q_i denoted by S_{Q_i} is the set of all those principals Q, such that $t_{Q_i,Q} \neq NULL$.

Definition 3 The *common peer vectors* of Q_i with Q_j are defined as:

$$\vec{C}_{Q_i,Q} = \left(t_{Q_i,Q_{k_1}}, t_{Q_i,Q_{k_2}}, \ldots, t_{Q_i,Q_{k_m}}\right), \text{ and } \vec{C}_{Q,Q_i} = \left(t_{Q_{k_1},Q_i}, t_{Q_{k_2},Q_i}, \ldots, t_{Q_{k_m},Q_i}\right)$$

where $\left\{Q_{k_1}, Q_{k_2}, \ldots, Q_{k_m}\right\} = S_{Q_i} \cap S_{Q_j}$.

Now, our evaluation metrics are precisely developed as following:

Peer Recommendation: Suppose there are n principals in the system: $Q_1, Q_2, \ldots, Q_n$. Each principle has a trust value for any other principal it interacted with before. The *common peer vectors* of Q_i with Q_j are defined as:

$$\vec{C}_{Q_i,Q} = \left(t_{Q_i,Q_{k_1}}, t_{Q_i,Q_{k_2}}, \ldots, t_{Q_i,Q_{k_m}}\right), \text{and } \vec{C}_{Q,Q_i} = \left(t_{Q_{k_1},Q_i}, t_{Q_{k_2},Q_i}, \ldots, t_{Q_{k_m},Q_i}\right)$$

where $\left\{Q_{k_1}, Q_{k_2}, \ldots, Q_{k_m}\right\} = S_{Q_i} \cap S_{Q_j}$.

[1] This work was supported by IITA Professorship for Visiting Faculty Positions in Korea from Ministry of Information and Communications. Dr Young-Koo Lee is corresponding author.

The *peer recommendation* for the interaction with Q_j to Q_i is defined as:

$$PR_{Q_i,Q_j} = \begin{cases} \left(\vec{C}_{Q_i,Q} \bullet \vec{C}_{Q,Q_j}\right)/m & , S_{Q_i} \cap S_{Q_j} \neq \phi \\ 0 & , S_{Q_i} \cap S_{Q_j} = \phi \end{cases} \quad \text{where, } m = \left| S_{Q_i} \cap S_{Q_j} \right|, \text{and } \vec{C}_{Q_i,Q} \bullet \vec{C}_{Q,Q_j} \text{ is the dot product}$$

Confidence: Let I_{Q_i} and I_{Q_j} denote the total number of interactions of principals Q_i and Q_j with all the principals in $S_{Q_i} \cap S_{Q_j}$. The *confidence* (*CF*) on the *PR* value for Q_i and Q_j as: $CF_{Q_i,Q_j} = \frac{1}{2}\left(f(m) + f\left(I_{Q_i}\right)\right)$, $CF_{Q_j,Q_i} = \frac{1}{2}\left(f(m) + f\left(I_{Q_j}\right)\right)$ where $f(x) = 1 - 1/(x+\alpha)$, we choose such *f(x)* since it approaches 1 as *x* becomes bigger, and α is an adjustable positive constant and can be tuned accordingly.

History of Past Interactions: The *Past Interaction Evaluation* (*PI*) of Q_j as calculated by Q_i is defined as: $PI_{Q_i,Q_j} = 1 - 1/(h_{Q_i,Q_j} + 1) = f\left(h_{Q_i,Q_j}\right), \alpha = 1$.

where $h_{Q_i,Q_j} = \max\left\{w_S SI_{Q_i,Q_j} - w_U UI_{Q_i,Q_j}, 0\right\}$ (w_S and w_U are positive numbers; the corresponding weights of SI_{Q_i,Q_j} and UI_{Q_i,Q_j}).

Time based evaluation: Intuitively, very old experiences of peers should have less weight in peer recommendation over new ones. Let $\tau_{P,Q}$ denotes the time stamp between *P* and *Q*, $\Delta\tau$ denotes the threshold time interval, and τ denotes the moment that Q_i and Q_j decide to interact. The time based evaluation (*TE*) for both Q_i and Q_j as: $TE_{Q_i,Q_j} = m / \left(\sum_{l=1}^{m} \left\lceil \Delta\tau_{Q_j,Q_{k_l}} / \Delta\tau \right\rceil\right)$, and $TE_{Q_j,Q_i} = m / \left(\sum_{l=1}^{m} \left\lceil \Delta\tau_{Q_i,Q_{k_l}} / \Delta\tau \right\rceil\right)$ where $\Delta\tau_{X,Y} = \tau - \tau_{X,Y}$.

Trust Evaluation Metric: Based on the aforementioned metrics, we are now ready to describe our trust evaluation metric. The trust metric is defined as a weighted arithmetic mean of *PR*, *CF*, *TE*, and *PI*. More precisely, the trust between two principals Q_i and Q_j who want to interact can be calculated as:

$$t_{Q_i,Q_j} = \left\{w_1\left(PR_{Q_i,Q_j}\right)\left(CF_{Q_i,Q_j} + TE_{Q_i,Q_j}\right)/2 + w_2\left(PI_{Q_i,Q_j}\right)\right\} / \left(\sum_{i=1}^{2} w_i\right)$$

where $w_i \in \mathrm{N}$ and they can be adjusted to a suitable value if more weight is to be given to a specific metric.

The calculation of the trust depends upon the recommendation of peer entities common to the entities which are weighted according to the number of past interactions and the time of last interaction. The model can calculate trust between two entities in situations both in which there is past experience among the interacting entities and in which the two entities are communicating for the first time. Several tuning parameters are suggested which can be adjusted to meet the security requirement of a distributed system. A highly secure system can adjust these parameters such that only a few entities with very high reputation and recommendation are allowed to perform requested actions.