Trust-based Service Composition and Binding with Multiple Objective Optimization in Service-Oriented Mobile Ad Hoc Networks

APPENDIX A

In this appendix, we provide details of trust propagation and aggregation in the single-trust baseline protocol design. A node receiving a trust update follows the propagation and aggregation protocol described below to update its (α, β) pair toward the SP. Trust propagation is done through recommendations received from 1-hop neighbors whom the trustor encounters dynamically. A node (trustor) will select n_{rec} recommenders whom it trusts most to provide trust recommendations of an SP (trustee). A recommender should only pass its direct interaction experience with the trustee node in terms of (α, β) as a recommendation to avoid dependence and looping [25]. Let node i be the trustor, node j be the trustee, and node k be a recommender. Also let $(\alpha_{i,j}, \beta_{i,j})$ be the trustor's (α, β) toward the trustee, $(\alpha_{k,j}, \beta_{k,j})$ be the recommender's (α, β) toward the trustee and $(\alpha_{i,k}, \beta_{i,k})$ be the trustor's (α, β) toward the recommender. Based on belief discounting (see [24] for details), node i will compute its new $(\alpha_{i,j}^{new}, \beta_{i,j}^{new})$ as follows:

$$\alpha_{i,j}^{new} = \alpha_{i,j} + \frac{2\alpha_{i,k}\alpha_{k,j}}{[(\beta_{i,k}+2)(\alpha_{k,j}+\beta_{k,j}+2)] + 2\alpha_{i,k}} \quad (14)$$

$$\beta_{i,j}^{new} = \beta_{i,j} + \frac{2\alpha_{i,k}\beta_{k,j}}{[(\beta_{i,k}+2)(\alpha_{k,j}+\beta_{k,j}+2)] + 2\alpha_{i,k}} \quad (15)$$

The basic idea is that if node i does not trust k, it will discount the recommendation provided by node k, so $\alpha_{i,j}^{new} \sim \alpha_{i,j}$ and $\beta_{i,j}^{new} \sim \beta_{i,j}$ as if the recommendation from k does not have any effect. This can be derived from (14) and (15). First of all, if node i does not trust node k then $\alpha_{i,k} \ll \beta_{i,k}$. In case node k is performing a bad-mouthing attack on node j, then $\alpha_{k,j} \ll \beta_{k,j}$. Applying these two conditions to (14) and (15), one can easily verify $\alpha_{i,j}^{new} \sim \alpha_{i,j}$ and $\beta_{i,j}^{new} \sim \beta_{i,j}$. In case node k is performing a ballot-stuffing attack on node j, then $\alpha_{k,j} \gg \beta_{k,j}$ and again one can easily verify $\alpha_{i,j}^{new} \sim \alpha_{i,j}$ and $\beta_{i,j}^{new} \sim \beta_{i,j}$. After trust aggregation, the trustor's (or node i's) trust toward the trustee (or node j) is then computed as $T_{i,j} = \frac{\alpha_{i,j}^{new}}{\alpha_{i,j}^{new} + \beta_{i,j}^{new}}$.

APPENDIX B

In this appendix, we provide implementation details of the ILP solution technique for optimally solving the node-to-service assignment problem with MOO in (9) of the main file for both trust-based and non-trust-based algorithms.

TABLE IV: Variable Definitions for ILP.

Variable	Definition
$ov_{p,q}$	1 if service requests O_p and O_q are overlapping in time; 0 otherwise
$s_{j,k}$	1 if node j can provide abstract service S_k; 0 otherwise
$tt_{j,k}$	1 if advertised service quality of node j satisfies the abstract service level minimum threshold of S_k; 0 otherwise
$in_{k,m}$	1 if service request O_m requires abstract service S_k; 0, otherwise
$to_{j,k,m}$	$s_{j,k} \times tt_{j,k} \times in_{k,m}$
$w_{j,k,m}$	1 if node j is assigned to service S_k in service request O_m; 0 otherwise

Table IV defines the variables used in the ILP formulation. There is only one decision variable, namely, $w_{j,k,m}$ to be determined by the ILP, specifying if node j should be assigned to abstract service k of service request m. The ILP will search for an optimal solution of $w_{j,k,m}$ for all j's, k's and m's to maximize MOO in both trust-based design and non-trust-based design algorithms. The objective function $MOO = \sum_{m \in \mathcal{T}} (\omega_{Q,m}\overline{Q}_m + \omega_{D,m}\overline{D}_m + \omega_{C,m}\overline{C}_m)$ as defined by (9) of the main file can be computed as a linear function of $w_{j,k,m}$ (the only decision variable to be decided by the ILP). The service-to-node assignment MOO problem is formulated as follows:

<u>Given</u>: $\mathcal{T}, \mathcal{S}_m, \mathcal{N}$

<u>Calculate</u>: $ov_{p,q}, s_{j,k}, tt_{j,k}, in_{k,m}$

<u>Find</u>: $w_{j,k,m}$

<u>Maximize</u>: $\sum_{m \in \mathcal{T}} (\omega_Q\overline{Q}_m + \omega_D\overline{D}_m + \omega_C\overline{C}_m)$

<u>Subject to</u>: $\forall j\ \forall \{p,q\}\ ov_{p,q} \times (w_{j,k,p} + w_{j,k,q}) \leq 1$;

$\sum_j w_{j,k,m} = in_{k,m}$; $w_{j,k,m} \leq to_{j,k,m}$

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