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***Abstract*—**
***Index Terms*—**

I. Introduction

II. System Model

[1] We consider an IoT cloud with two type of players:

1) End users, who want to process their sensors' data and send results to actuator.
2) IaaS providers, who provide computational resources for end users.

We consider that measuremnts of sensors for service s are performed and sent to processing units by rate of $\sum_{i=1}^{N_I} r_{i,s}$ and $r_{i,s}$ is sampeling rate processed by IaaS provider i for service s, hence we use $\log(\sum_{i=1}^{N_I} r_{i,s})$ as a quality of experience measurement for user of service s. Let p_i be the price that should be paid to IaaS provider i for unit of processing power and F_s be the processing power required for each sensor sample of user s. Then $p_i r_{i,s} F_s$ is price paid to IaaS provider i by user of service s and total cost for user of service s is $\sum_{i=1}^{N_I} p_i r_{i,s} F_s$. We define utility function for user of service s as the difference between quality of experience indicator and his total cost:

$$\varphi_s(R_s) = \log(\sum_{i=1}^{N_I} r_{i,s}) - \sum_{i=1}^{N_I} p_i r_{i,s} F_s \tag{1}$$

Where R_s is $[r_{1,s}, \dots, r_{N_I,s}]$ and $\lambda_{i,s}$s are descision variables for user s. We assume that each user's serivce is characterized by its mean response time and it should be greater than R_s^{max} to meet user's requirements. Mean response time for service s can be calculated as:

$$t_s = \frac{1}{\sum_{i=1}^{N_I} r_{i,s}} \sum_{i=1}^{N_I} r_{s,i}(t_{i,s}^{sensors} + t_{i,s} + t_{i,s}^{actuators}) \tag{2}$$

Where $t_{i,s}^{sensors}$ and $t_{i,s}^{actuators}$ are network delays from sensors to IaaS provider i and from IaaS provider i to actuator and $t_{i,s}$ is mean response time for service s at IaaS provider i. From queueing theory we know that for a M/M/1 queue with arival rate λ and service rate μ, mean response time is $\frac{1}{\mu-\lambda}$. If we assume that C_i is processing capasity of IaaS provider i and $u_{i,s}$ is utilizaion of IaaS provider i by service s then for service s on IaaS provider i arival rate is $r_{i,s} R_s$ and service rate is $u_{i,s} C_i$, So $t_{i,s}$ can be written as follow:

$$t_{i,s} = \frac{1}{u_{i,s} C_i - r_{i,s} F_s} \tag{3}$$

Which should be greater than r_s^{min}. To prevent IaaS provider from being saturated for user of service s we consider that $r_{s,i} F_s \leq 0.9 u_{i,s} C_i$. Therefore each user try to solve following optimization problem:

$$\max_{\Lambda_s} \varphi_s(R_s) \tag{4a}$$

subject to:

$$R_s^{min} \leq \sum_{k=1}^{N_I} r_{k,s} \tag{4b}$$

$$0 \leq r_{j,s}, \forall j \in \{1, \dots, N_I\} \tag{4c}$$

$$r_{j,s} R_s \leq 0.9 u_{j,s} C_j, \forall j \in \{1, \dots, N_I\} \tag{4d}$$

$$t_{j,s} + \frac{1}{u_{j,s} C_j - r_{j,s} F_s} \leq 0 \tag{4e}$$

We consider two types of IaaS providers:

1) Usual servers placed in datacenters which has vast amount of computational power.
2) Wireless sensor gateways placed near sensors which has limited computational power, but may have less transmition delay.

IaaS providers are paid for their processing power so their revenue is sum of all revenue come from services that has non-zero $\lambda_{i,s}$ and they pay for their electric power consumption. So we define utility function of IaaS provider i as follow:

$$\varphi_i(p_i, U_i, \Lambda_S^i) = \sum_{s=1}^{N_S} p_i \lambda_{i,s}^i R_s - P^{electrical}(P_i(\sum_{s=1}^{N_S}(u_{i,s}))) \tag{5}$$

Where $u_{i,s}$ is utilization of IaaS provider i assigned to user service s, U_i is $[u_{i,1}, \dots, u_{i,N_S}]$ and Λ_S^i is conjector of Λ_S by IaaS provider i. In this paper we consider that electrical power of IaaS provider i is a function of its total utilization. We denote this function by $P_i(u_i)$ and as assumed in [1], we can write $P_i(.)$ as:

$$P_i(u_i) = P_i^{idle} + (P_i^{max} - P_i^{idle}) u_i \tag{6}$$

So each IaaS provider try to solve following optimizaiton problem:

$$\max_{p_i, U_i, \Lambda_S^i} \varphi_i(p_i, U_i, \Lambda_S^i) \tag{7a}$$
subject to:
$$0 \le u_s^i, \forall s \in \{1, \ldots, N_S\} \tag{7b}$$
$$\sum_{s=1}^{N_S} u_s^i \le 1 \tag{7c}$$
$$P_{idle}^i + (P_{max}^i - P_{idle}^i) \sum_{s=1}^{N_S} u_s^i \le \bar{P}^i \tag{7d}$$
$$\Lambda_s^i \in SOL(F_s), \forall s \tag{7e}$$

We can define an exact potential function for this game. As explained in ** function π is an exact potential function if for — we have:

$$\pi(x^i, x^{-i}) - \pi(y^i, x^{-i}) = \varphi_i(x^i, x^{-i}) - \varphi_i(y^i, x^{-i}) \tag{8}$$

It's easy to show that any global minimum of function π is a nash equilibrium of corresponding game.

show or not??? For IaaS providers exact potential function can be writen as:

$$\pi(x^i, x^{-i}) = \sum_{i=1}^{N_I} \varphi_i(x^i, x^{-i}) \tag{9}$$

III. Problem Formulation

$$\max_{p^i, U^i, \Lambda_S^i, \sigma_S^i, \gamma_S^i, \nu_S^i, , \eta_S^i} \varphi(p_i, U^i, \Lambda_S^i) \tag{10a}$$
subject to:
$$\sum_{s=1}^{N_S} u_s^i \le 1 \tag{10b}$$
$$0 \le u_s^i, \forall s \in \{1, \ldots, N_S\} \tag{10c}$$
$$P_{idle}^i + (P_{max}^i - P_{idle}^i) \sum_{s=1}^{N_S} u_s^i \le \bar{P}^i \tag{10d}$$
$$0 \le \lambda_{s,i}^i \tag{10e}$$
$$\lambda_s^{min} - \sum_{j=1}^{N_I} \lambda_{j,s}^i \le 0, \forall s \in \{1, \ldots, N_S\} \tag{10f}$$
$$\lambda_{j,s}^i R_s \le 0.9 \mu_{j,s} C_j, \forall s \& j \tag{10g}$$
$$\begin{aligned}\sum_{j=1}^{N_I} \lambda_{j,s}^i (t_{j,s}^{sensors} + \frac{1}{\mu_{j,s}^i - \lambda_{j,s}^i} + t_{j,s}^{actuators} - t_s^{\max}) \\ \le 0, \forall s\end{aligned} \tag{10h}$$
$$\sigma_{j,s}^i \lambda_{j,s}^i = 0, \forall j \& s \tag{10i}$$
$$\gamma_s^i (\lambda_s^{min} - \sum_{j=1}^{N_I} \lambda_{j,s}^i) = 0, \forall s \tag{10j}$$
$$\nu_{j,s}^i (\lambda_{j,s} R_s - 0.9 \mu_{j,s} C_j) = 0 \forall j \& s \tag{10k}$$
$$\begin{aligned}\eta_s^i \sum_{j=1}^{N_I} \lambda_{j,s}^i (t_{j,s}^{sensors} + \frac{1}{\mu_{j,s} C_j - \lambda_{j,s} R_s} + t_{j,s}^{actuators} - t_s^{\max}) \\ = 0, \forall s\end{aligned} \tag{10l}$$
$$\begin{aligned}&\frac{1}{\sum_{k=1}^{N_I} \lambda_{k,s}^i} - p_j R_s + \\ &\sigma_{j,s}^i + \gamma_s^i - R_s \nu_{j,s}^i - \\ &\eta_s^i (t_{j,s}^{sensors} + t_{j,s}^{actuators} - t_s^{max} + \frac{\mu_{j,s} C_j}{\mu_{j,s} C_j - \lambda_{j,s}^i R_s}) \\ &= 0, \forall s \& j\end{aligned} \tag{10m}$$
$$0 \le \sigma_{j,s}^i, \sigma_{j,s}^i, \nu_{j,s}^i \& \sigma_{j,s}^i, \forall s \& j \tag{10n}$$

Here $\lambda_{s,i}$ is $[\lambda_1^i, \cdots, \lambda_{N_S}^i]$ and λ_s^i is conjecture of λ_s by PaaS provider i, u^i is $[u_{i,1}, \cdots, u_{i,N_S}]$ and $u_i = \sum_{i=1}^{N_S} u_{i,s}$. A potential function can be defined for this game.

Function π is potential function of this game:

$$\pi(x^i, y^i, x^{-i}, y^{-i}) = \sum_{i=1}^{N_I} P(u_i) - p_i u_i \tag{11}$$

here x^i and y^i are a tuple of (p^i, u^i) and $(\lambda_{s,i}, \nu_S^i, \gamma_S^i)$

References

[1] L. C. C. Dupont, R. Giaffreda, "Edge computing in iot context: horizontal and vertical linux container migration," *Global Internet of Things Summit (GIoTS)*, 2017.