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***Abstract*—**

***Index Terms*—**

I. Introduction

II. System Model

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

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

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

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

subject to:

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

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

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

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

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

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

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:

$$0 \le u_s^i, \forall s \in \{1, \ldots, N_S\} \tag{7b}$$

$$\sum_{s=1}^{N_S} u_s^i \le 1 \tag{7c}$$

$$P_{idle}^i + (P_{max}^i - P_{idle}^i) \sum_{s=1}^{N_S} u_s^i \le \bar{P}^i \tag{7d}$$

$$\Lambda_s^i \in SOL(F_s), \forall s \tag{7e}$$

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

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:

$$\sum_{s=1}^{N_S} u_s^i \leq 1 \tag{10b}$$

$$0 \leq u_s^i, \forall s \in \{1, \ldots, N_S\} \tag{10c}$$

$$P_{idle}^i + (P_{max}^i - P_{idle}^i) \sum_{s=1}^{N_S} u_s^i \leq \bar{P}^i \tag{10d}$$

$$0 \leq \lambda_{s,i}^i \tag{10e}$$

$$\lambda_s^{min} - \sum_{j=1}^{N_I} \lambda_{j,s}^i \leq 0, \forall s \in \{1, \ldots, N_S\} \tag{10f}$$

$$\lambda_{j,s}^i R_s \leq 0.9 \mu_{j,s} C_j, \forall s \& j \tag{10g}$$

$$\sum_{j=1}^{N_I} \lambda_{j,s}^i (t_{j,s}^{sensors} + \frac{1}{\mu_{j,s}^i - \lambda_{j,s}^i} + t_{j,s}^{actuators} - t_s^{\max}) \leq 0, \forall s \tag{10h}$$

$$\sigma_{j,s}^i \lambda_{j,s}^i = 0, \forall j \& s \tag{10i}$$

$$\gamma_s^i (\lambda_s^{min} - \sum_{j=1}^{N_I} \lambda_{j,s}^i) = 0, \forall s \tag{10j}$$

$$\nu_{j,s}^i (\lambda_{j,s} R_s - 0.9 \mu_{j,s} C_j) = 0 \forall j \& s \tag{10k}$$

$$\eta_s^i \sum_{j=1}^{N_I} \lambda_{j,s}^i (t_{j,s}^{sensors} + \frac{1}{\mu_{j,s} C_j - \lambda_{j,s} R_s} + t_{j,s}^{actuators} - t_s^{\max}) = 0, \forall s \tag{10l}$$

$$\begin{aligned} &\frac{1}{\sum_{k=1}^{N_I} \lambda_{k,s}^i} - p_j R_s + \\ &\sigma_{j,s}^i + \gamma_s^i - R_s \nu_{j,s}^i - \\ &\eta_s^i (t_{j,s}^{sensors} + t_{j,s}^{actuators} - t_s^{max} + \frac{\mu_{j,s} C_j}{\mu_{j,s} C_j - \lambda_{j,s}^i R_s}) \\ &= 0, \forall s \& j \end{aligned} \tag{10m}$$

$$0 \leq \sigma_{j,s}^i, \sigma_{j,s}^i, \nu_{j,s}^i \& \sigma_{j,s}^i, \forall s \& j \tag{10n}$$

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