ARTA: An Economic Middleware to Exchange Pervasive Energy and Computing Resources

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***Abstract*—Studies reveal that an integrated system of smart grid and cloud computing ecosystems can better attain the energy efficiency objectives, considering all the aspects, e.g. resource utilization, energy saving and carbon efficiency. To facilitate the integration, in this paper, we introduce an agent-oriented economic middleware architecture (ARTA) to exchange pervasive energy and computing resources in different layers of the service provisioning platform, from the edge layer of micro-grid and P2P-cloud to the mass production layer of the giant power plants and data centers. ARTA follows a semi-decentralized economic model by operating through partial system view in the edge-layer negotiations and considers system dynamics and uncertainties in the agents decisions.**

I. INTRODUCTION

Smart grid is becoming essential in moving toward modern, sustainable life architecture. To roll-out smart grid, Information and Communication Technology (ICT) infrastructure is required as computing and communication platforms. On-the-other-hand, energy has been amounted to increasingly significant portion of operational expenditure in the ICT sector. Hence, attaining the energy efficient service provisioning targets is the first class goal in shaping contemporary ICT platform. Further to designing energy efficient hardware infrastructures and services, energy source awareness fosters developing an energy efficient ICT platform. As a result, energy efficient ICT and ICT for deploying an efficient energy system are tightly coupled, and an integrated platform of smart grid and ICT can fulfill the energy efficiency goals.

To this end, in our previous work [1], we qualitatively compared the smart grid and cloud platform and outlined the potential benefits of such an integrated platform. There is a line of work centered on exploiting the cloud and peer-to-peer platforms for the smart grid computing [2]–[5]. In a cloud computing environment, flexible data centers offer scalable computing, storage and network resources to any Internet-enabled device on demand. Moreover, P2P-cloud can manage the massive amount of data from distributed sources of consumption, generation and network nodes. On the other hand, diverse energy sources of smart grid improve the availability, sustainability and environmental friendliness of the cloud platform.

We proposed the Cloud of Energy (CoE) architecture in [6], which envisages the service provisioning framework of the future that provides everything as a service via an integrated cloud and smart electricity grid system in horizontal and vertical dimensions. CoE facilitates the resource management in each element of the smart grid and cloud through their hierarchy. It also expedites the horizontal integration of different services via their shared economic incentives. Integration promotes the collaboration of a diverse range of providers and consumers, requesting for different services. Moreover, an integrated system is more efficient and greener, since it avoids unnecessary redundancy in the common sub-systems, such as shared data, computing and communication infrastructure, etc. In addition, the integration contributes to a greener system due to the energy source awareness.

CoE aims to design a service framework that incentivizes all range of service producers, offering services from computing to energy, in the range of small prosumers to giant providers, to serve in an energy-aware marketplace, via an economic middleware. In tandem with CoE goals, in this work, we introduce the requirements of an economic middleware to translate a service in every concept, e.g. energy and computing in CoE, to the common incentive scale of money. This middleware outlines an Agent-oriented Resource Trading Architecture (ARTA), and the associated economic model. This economic model needs to meet the scalability requirement of CoE system and it should cope with the dynamic nature of this system.

The major contribution of this paper is portraying ARTA middleware which is mapped to the CoE layered architecture, the overview of the agent-oriented system is given in the next section. In Section III, we highlight the market rules and the economic model offered by ARTA. The economic model is inspired by the cloud economics [7], combined with the Peer-to-Peer management protocols [8]. The distinguishing feature of the economic model is relying on partial information and considering system dynamics. Section V assesses the ARTA's feasibility. Evaluation results indicate that although agents have partial view of the system due to semi-decentralized negotiation protocol, ARTA performs yet efficient, while it is more robust to system dynamics and uncertainties. We close the paper in Section VI.

II. AGENT-ORIENTED SYSTEM OVERVIEW

ARTA is modeled with the concept of multi-agents, since the autonomous resource agents are distributed all through the edge layer and the hierarchy of the system. Agents are autonomous computing and/or electricity prosumers (producer/consumer) systems that are capable of making decisions

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independently and interacting with the other agents through cooperation by working together and drawing on each others knowledge and capabilities. They can achieve the state in which their actions fit in well with the others via coordination, or negotiate to reach agreements on some matters [9].

Multi-agent systems are the most suitable platform to model the distributed collaborative systems requirements based on their properties and functionality, allowing them to implement intelligence in the smart grid control due to their social ability, flexibility, self-healing features and economic agent support [10]. Moreover, agent-oriented computing provides a natural paradigm for automating the interactions among complex interconnected systems. Therefore, we frame the economic middleware conforming agent-oriented architecture, with the following description.

a) Environment: In ARTA, we have nested environments through the hierarchy of the architecture, which amount to a set of producers and consumers, and brokers. Looking closer, prosumers make a rich, heterogeneous environment which is controlled by coordinators, in order to drive the prosumers behavior and represent the interest of a group of prosumers on the market.

b) Agents: Agents include prosumers, brokers in different levels, mass producers of electricity and cloud services (in the mass production layer). **Prosumer** agents produce services in the retail level and are the end users of the services, at the same time. Prosumers are mapped to household and business entities, in the edge layer and mass producers are cloud and electricity providers in the mass production layer. Each prosumer is equipped with a cloud and electricity controller, to regulate and control its demand and supply.

Broker agents in different layers can decide what strategies to employ both on the market and prosumers. Each **local broker** is authorized to run its own market regulation mechanism to supply the demands locally, as long as it does not violate the wholesale market's framework. This elevates the decentralization, better scalability and speed of adjustment to varying local conditions, while bounding global imbalances. Local broker is mapped to a household or any energy prosumer which is selected according to the required capabilities of the system. Utility and cloud service providers can trade the mass provider services on their behalf via the **mass production broker**. Note that mass production broker is a new concept in our model, which combines or links the utility providers and cloud brokers to form a new broker agent which is capable of brokering both energy and computing services.

c) Market Rules: Since energy and computer systems provide two different services, to integrate these two systems, in our market model, we need a metric that can measure the contribution of each service in an understandable scale for the other. Moreover, a universal metric facilitates the collaboration of the two systems. Virtual money seems to be an appropriate metric for this end.

1) *Local Currency:* Defining local currency in the micro-grid-community level can incentivize the users to collaborate in the system by sharing the resources, i.e. energy and computing by earning credits. The idea behind defining a local currency is to drive and improve the coordination of users within a vicinity and promote the vicinity among the others by elevating the value of its local currency against them. Moreover, this mechanism helps in load balancing by changing the value of local currency, via allowing arbitration.
2) *Redeeming the value of idle resources:* When local supply exceeds the local demand, the local broker can assign bitcoin [11] generation tasks to the prosumeres offering resources, in exchange of certain amount of local currency based credit in their account. Therefore, the *available resources are not effectively lost and can be re-acquired later from mass producers*, if supply is scarce in the vicinity. This is specially useful when the *energy powering the idle resources is green energy that is being under-utilized*. Thus, we can in a novel way, *effectively attempt at preserving resources and energy as effective reserves for later demand*.
3) *Resource provisioning from outside the vicinity:* Local brokers, to provide resources from outside the vicinity, can only rely on some outside currency, i.e. the bitcoin generated in the vicinity when there are excess resources of electricity and computing in the vicinity (as an ideal universal replacement to any legal tender or precious metal). Afterwards, to deliver the service to the end user, local broker charges the users based on the local currency value equivalent to the amount of bitcoin and the associated conversion taxes.
4) *Pricing mechanism:* In order to encourage the agents to provide resources locally, an adaptive tax rate is defined. Tax is applied to the services provided from outside the vicinity. Therefore, users are incentivized to acquire their resources from inside the vicinity. However, to preserve the service quality, in case of resource scarcity or unreliability due to system dynamics and uncertainties, the tax rate is decreased.

III. ECONOMIC MODEL

In this section we highlight the appealing economic model requirements and specifications. Then we portray the protocols and mechanisms designed to form the economic model.

A. System Requirements

An economic model enabling the resource trading in the CoE system should address the following CoE system requirements.

- **Perishable Resources:** computing and energy resources available in each moment are not storeable; hence, resource capacities not utilized now are worthless in the next moment. We cannot store the computing capacity when it is idle to exert it later when needed. Besides, the overhead of keeping the idle resources standby or switching the idle capacity to sleep mode in terms of energy and latency, makes the model to design some mechanisms to address this issue. ARTA tackles this problem by aligning the demand to the available resources.
- **System Dynamics:** In the edge layer of the system, resources are volatile due to the system uncertainties.

Uncertainty is rooted in the prosumers' natural behavior, as long as they can choose to contribute to the system or leave it. Moreover, the unpredictability in the renewable energy production aggravates the problem. Therefore, the economic model should be robust enough to cope with the dynamic resource availability.

B. Model Specifications

By using market mechanisms, we can regulate supply and demand. ARTA follows this goal by decreasing the gap between demand and supply patterns, through adopting the negotiation and auction strategies proposed in economics. The major differences of negotiation and auction are highlighted in [12]. Whereas the auction is established by a third-party entity to determine the value of an object with an unknown value, negotiation focuses on creating value through making concession. In other words, negotiation is a form of collaborative decision making with at least two entities actively involved in the process. The negotiating agents cannot fulfill their goals unilaterally; hence, they have to achieve a compromise [13].

ARTA offers a bi-level resource provisioning strategy which includes two protocols, each following a different economic model, yet can co-operate with each other to improve the ARTA's performance and scalable implementation. A negotiation based protocol (*horizontal protocol*) is provided to exchange the resources in the edge layer, i.e. locally in each vicinity. The prosumer agents negotiate directly to supply and provide the resources locally. This negotiation is initiated by the local broker of the vicinity and goes on throughout the direct communication of the negotiation agents. Moreover, in the case of local resource scarcity, resources should be acquired externally from the mass production layer, via the distribution layer broker. To this end, a double auction mechanism is exerted to devise a *vertical protocol*.

C. Horizontal Negotiation Protocol

This protocol is run in the edge layer, to facilitate the Prosumer-to-Prosumer (P2P) negotiation. Negotiation between each pair of prosumers is performed by making proposal in iterative rounds until either an agreement is reached or at least one of the negotiating agents misses the deadline. The service deadline is defined according to the service flexibility/availability.

Note that this negotiation can be many-to-many due to the multilateral nature of the CoE system. Viz. each prosumer agent can negotiate deals with multiple prosumers simultaneously.

a) Negotiation Policy: Each prosumer considers the following specifications and quantifies them according to its desires, conforming the strategies formulated here.

- **Initial Price** identifies the most reasonably desirable price that an agent is willing to sell or buy the services. Each agent defines its initial price P_i^0, independently, and according to the system feedback.
- **Reserved Price** indicates the max/min price that an agent inclines to exchange the money/resources, P_i^r.
- **Service Deadline:** By defining a time dependent bargaining strategy, an agent considers the deadline in the negotiation. τ_i stands for the service/resource deadline. The closer the service is to the deadline, the faster the negotiation price converges to the reserved price.
- **System Dynamics:** λ coefficient is defined to pace the negotiation according to the service specifications as well as system dynamics. In order to consider the system dynamics, we define a feedback presenter $s(t)$ in the range of [0-1] which is sent regularly to the prosumers from the broker. The lower the value of $s(t)$, the more dynamic the system. $s(t)$ is computed in the feedback generator following (1). $s(t)$ is calculated based on the normalized ratio of the number of the prosumers in the vicinity to the average number of prosumers over time, and the difference of the currently available prosumers and the prosumers in the previous round, if the number is decreased. In (1), $n(t)$ represents the number of the prosumers connected to the vicinity at time t. $\bar{n}$ denotes the average number of prosumers over time, so far.
  Feedback is sent to the prosumers in each round exploiting a gossip protocol [14]. The probability of gossip exchange is defined according to the entropy of the information to transmit, $P_{forward}(t) = 1 - |s(t) - s(t-1)|$. The bigger the gap between $s(t)$ and $s(t-1)$, the more effort is required to update the feedback throughout the vicinity. Hence, the update is triggered in all nodes, only if the system state is significantly changed compared to the previous round. This way, we can control the system overhead. Loosely paraphrasing, if there is little change in the $s(t)$ value, relying on the previous value, $s(t-1)$ does not make remarkable changes in the agents decision. Therefore, they can remain using the previous feedback, and save message exchanges in the network. By default, if a prosumer does not receive feedback in round t, it replaces $s(t)$ by $s(t-1)$.

$$s(t) = \frac{1}{2}\left(\frac{n(t)}{\bar{n}} + \frac{max(0, n(t) - n(t-1))}{n(t)}\right) \qquad (1)$$

- **Market Perception** β_i is computed by each agent i to evaluate its price proposals compared to the offers it receives from the provider agents, it is negotiating with. Market perception is calculated using (2). In this formula, the average ratio of immediate changes in the providers proposals to the average proposal change over time is considered to estimate the market perception of each consumer agent i, which is in negotiation with $|providers_i|$ provider concurrently. $|providers_i|$ represents the cardinality of the providers' set an agent is negotiating with. Note that each consumer agent has only partial view of the system and calculates the market perception accordingly.

$$\beta_i(t) = \frac{1}{|providers_i|} \sum_{j \in \{1,2,\ldots,|provider|\}} \frac{P_j(t-2) - P_j(t-1)}{\frac{P_j^0 - P_j(t-1)}{t}} \qquad (2)$$

b) Negotiation Strategy: During the negotiation, each consumer proposes a price which varies in each round. At first, it starts by P^0 and adopts the value according to the service deadline and system dynamics, as depicted in (3).

$$P_i(t) = P_i^0 + (\frac{t}{\tau_i})^{\lambda_i(t)}(P_i^r - P_i^0) \tag{3}$$

In (3), t denotes the time elapsed from the beginning of the negotiation, and τ_i is the service deadline. Term $\frac{t}{\tau_i}$ represents the time left for providing the resource; thus, the closer the deadline, the more increase in the proposed price. Further to the service deadline, system dynamics and market perception affect the proposed price. Therefore, λ coefficient should be adapted dynamically during the negotiation, as shown in (4).

λ_i^{min} is applied to avoid unnecessarily utility losses, due to too rapid conceding. The rational behind this strategy to choose the $\lambda_i(t)$ coefficient is that a consumer can tune its proposals according to the market perception. Looking closer, loosing the market position according to the perception leads to faster λ adjustment, while being more stable in the market (increasing $\beta_i(t)$) results in slower changes in $\lambda_i(t)$. All the same, the more stable the system is, the higher the probability of finding resource provider for negotiation; therefore, the slower changes in $\lambda_i(t)$ value. In contrast, in less stable system situation, the negotiation should be finished before the resources disappear from the system; hence, the convergence to the P_i^r happens more quickly.

c) Producer Side Negotiation Strategy: Producer follows the same strategy as the consumer in the system, but it decrease the proposed price instead of increasing it, i.e. $P_j^0 \geq P_j(t) \geq P_j^r$. Thus, the pricing follows the formula below.

$$P_j(t) = P_j^0 - (\frac{t}{\tau_j})^{\lambda_j(t)}(P_j^0 - P_j^r) \tag{5}$$

Each prosumer can decide about their own prices in each round of auction according to the exponential increase/decrease policy indicated as λ, which is in range of zero to one. The closer the deadline to provide the service (τ), the higher/lower the requester's/supplier's proposed price will be. P^0 represents the initial price, and P^r/P^0 is the maximum and minimum price to offer, respectively.

d) Protocol Truthfulness: To incentivize the suppliers to negotiate truthfully in the system, each requester, when the negotiation ends, rates the supplier. These rates are collected by the local broker to rank the suppliers. The higher rank suppliers are more favorable in the future negotiation initializations.

D. Vertical Auction Protocol

In the distribution layer broker, as visualized in Figure 1, a double auction module exist. A double auction mechanism facilitates the resource exchange between mass production layer and the consumers at the edge of the system, pursuing the traditional utility providers' model.

a) Biding: Every edge-layer and mass production layer provider offers a bid to the distribution layer broker. The bid from each agent A_i is in the form of a tuple b_i with four entries, resource type θ_i, resource amount q_i, the price per unit resource p_i and a flag f_i that indicates if the agent provides the resource or request it. Note that each agent can only submit one bid of the same resource at each round $\forall_{i,j}\theta_i = \theta_j \Rightarrow b_i = b_j$; otherwise, all the bids for the same resource type from that agent are deleted before running the auction step. Moreover, to help preventing malicious bids, p_i should be greater than a pre-defined threshold, otherwise the bid is rejected before running the auction.

b) Auction: The auction follows the sealed price mechanism; therefore, each participant is only aware of its own proposal. After collecting all bids, distribution layer broker sorts all the bids according to the proposed prices ascendingly for the providers and descendingly for the requesters. Then a double auction runs in the auctioneer module and the results are announced to the participants. All the unsuccessful bids should be revised and resubmitted in the next round.

IV. ARTA MIDDLEWARE

An Economic Middleware acts as an interface to facilitate smart electricity and computing service trading across the CoE hierarchy and horizontally in the edge layer. This middleware, as shown in Figure 1, includes the following components:

- *Energy Controller(EC):* This module exists in each prosumer side, and is able to predict and measure the energy consumption of each appliance at home.
- *Computing Controller(C2):* In each prosumer of the edge layer, C2 plays the same role of EC for the computing services.
- *Local broker:* It is responsible for defining the tax rate based on the difference of the demand and local supply it receives. If the demand and supply do not match and the vicinity encounters resource scarcity, the broker decreases tax rate, through **tax controller**, to make the external resources more affordable for the end users. Moreover, the broker should submit the bids to the higher level broker, to obtain the resources for excess demand of the vicinity. This task is performend in the **bid generator** module. A **bitcoin repository** component is responsible to keep the bitcoin balance of the vicinity which is necessary for trading with mass production broker, in the outside world. Bitcoin [11] is an online payment system, in which trade parties can transact directly without the interference of any intermediary, through bitcoin. Prosumers submit all the demands and the offered resources to the local broker. It is the responsibility of the broker to find the matching supply and demands; thus, initiate the negotiation between them, by proposing the list of tentative matching prosumer agents. Besides, local broker provides feedback to the different modules inside it, via collecting data from each module and generating feedback by means of **feedback generator**. Some feedback about the system overview is also sent to the prosumers in the vicinity to cover the partial view that each prosumer sketches from the system.
- **Mass production broker:** This agent is in charge of collecting bids and setting up auctions among different service providers of mass production layer for the demands submitted by the local brokers. It is

$$\lambda_i(t) = \begin{cases} \lambda_i(t-1)+\beta_i(t-1)+s(t) & \lambda_i(t-1)>1 \\ max(\lambda_i^{min}, \lambda_i(t-1)+(\beta_i(t-1)+s(t))(\lambda_i(t-1)-\lambda_i^{min})) & 0<\lambda_i(t-1)\le 1 \end{cases} \tag{4}$$

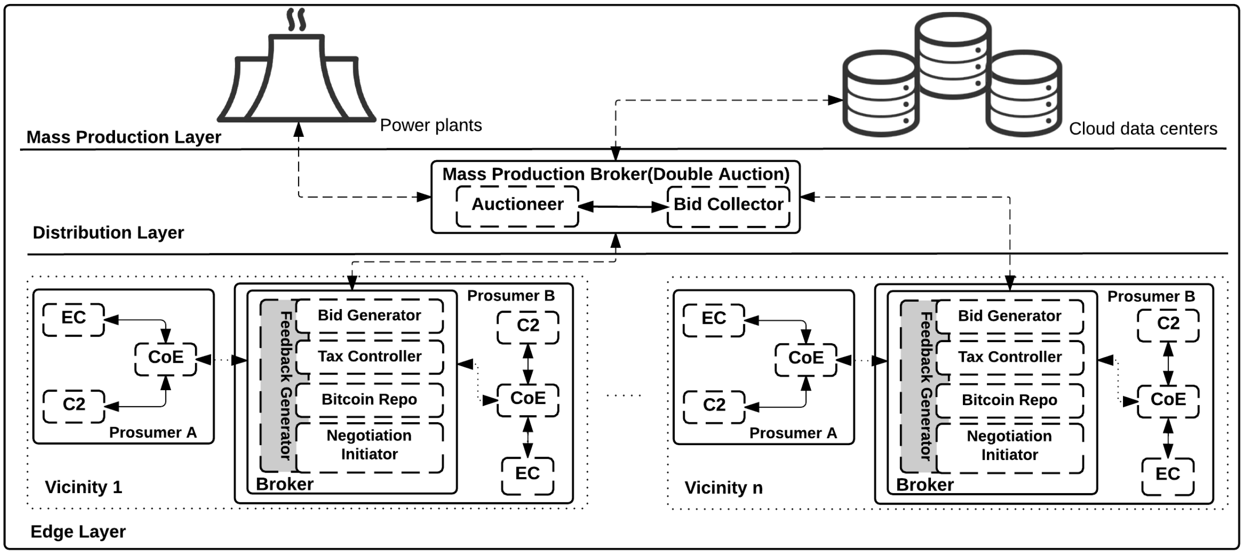

Fig. 1: Economic Middleware Architecture

composed of two major components of **bid collector** and **auctioneer**.

V. EVALUATION FRAMEWORK

We elaborate the feasibility of the ARTA middleware architecture as well as the efficiency of the economic model across this section.

A. Experiment Setup

Our evaluation is based on the simulation of different vicinity sizes, from 0 to 500 nodes and the default vicinity size is set to 100 nodes. We study the effect of system dynamics under different scenarios of system stability and resource availability is studied by considering diverse range of demand to supply ratios as well as resources and demands with different deadlines. In our evaluation we assume $\lambda_{min} = 0.1$.

B. Economic Model Efficiency

Efficiency of the economic model is defined as the amount of the demand served inside the vicintiy. As depicted in Figure 2, with the demand to supply ratio in the range of 10%-45% ARTA performs more efficiently due to the enough resource availability in the system. The success rate of the negotiations in this range is over 90%. However, increasing the demand to supply ratio leads to resource scarcity and therefore, the model cannot work efficiently in those cases. In demand to supply ratio of below 10%, efficiency is very low, because of underutilized resources. Moreover, as shown in Figure 2, the more stable the system, the higher the gained efficiency.

C. Negotiation Protocol Overhead

As stated, to tackle system dynamics in each round of the negotiation, the system stability parameter is updated proactively. However, to prevent the redundancy which leads to excess overhead in the system, we applied a gossip control mechanism that exchanges the messages according to the entropy of the information. Therefore, the more stable the network, the lesser messages to exchange. Figure 2 confirms this statement, by producing zero overhead when the system is perfectly stable, i.e. $s(t) = 1$. This protocol runs the proactive updating with reactive overhead. Therefore, even in the worst case ($s(t) = 0$), the overhead grows linearly by increasing the vicinity dimensions and remains under 20%, in the vicinity of smaller than 100 nodes.

D. Middleware Scalability

As illustrated in Figure 3, in case that the system does not experience high resource dynamicity, i.e. $S \geq 0.5$, the overhead of middleware maintenance increases linearly by increasing the vicinity size, but it is still below 50%. Very stable system confronts overhead of less than 10% in a very large vicinity. However, we notice that even in the case of highly dynamic system, a vicinity of 100 nodes can survive by producing the overhead of less than 20%.

Implication: Shrinking the vicinity size in highly dynamic situations improves the system sustainability.

VI. CONCLUSION

In this paper, we portrayed the ARTA economic middleware to introduce the economics of an integrated energy and computing resource trading via an agent-oriented architecture. ARTA middleware facilitates the resource exchange in the edge-layer of the system, i.e. micro-grid and P2P-cloud layer,

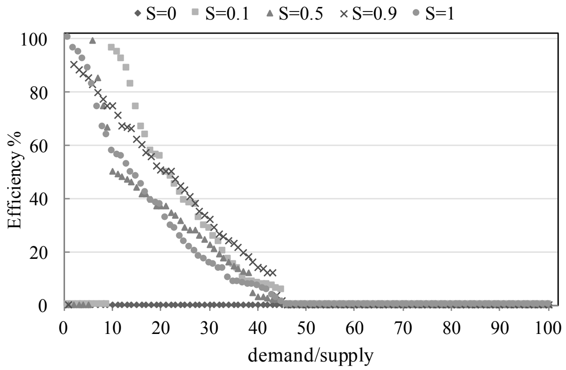

Fig. 2: Negotiation Protocol Efficiency

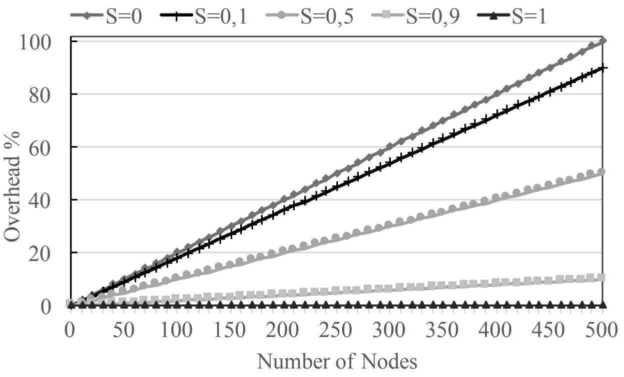

Fig. 3: Negotiation Protocol Scalability

as well as, through the system hierarchy from mass production layer to the end-users at the edge of the system. Evaluation results indicate that ARTA performs efficiently during the negotiations due to employing the information each prosumer provides independently about the system, although it is a partial view. ARTA is robust due to the semi-decentralized negotiation protocol at the edge and also considering system dynamics in each agents decision. Moreover, it follows the traditional auction based mechanism to provide resources in the system hierarchy, which matches this emerging economic model with legacy systems. However, this work only sketches a prototype of the economic middleware. As future work, we intend to extend the technical requirements that ARTA should meet.

Considering CoE architecture, in the edge layer of the system, vicinity size plays a significant role in promoting the energy efficiency within the vicinity. Increasing the resource availability leads to more static power dissipation. Thus, as future work in line with ARTA's goals, specially in case of underutilized resources, where excess resources induce energy non-efficiency in the system, resizing the vicinity dynamically can contribute to increasing the overall energy efficiency. Dynamic vicinity sizing should adhere the demand and uncertainties in the system to obtain the demands efficiency. Conjointly with the techniques offered to align the demand with the supply, vicinity sizing can decrease the demand and supply gap by regulating the supply according to the demand.

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