Automated Negotiation of Smart Contracts for Utility Exchanges between Prosumers in Eco-Industrial Parks

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Abstract. Peer-to-Peer (P2P) Markets of prosumers trading utility surpluses (e.g., heating, cooling, or electric power) is a plausible realization of industrial symbiosis for companies in Eco-Industrial Parks (EIPs) in order to reach significant economic benefits and cut emissions. Through the synergistic co-generation and trading of utilities and industrial services, a P2P Market design makes room for socially desirable behavior despite the inherent selfish nature of each prosumer company. In this paper, a P2P Market prototype for the automated negotiation of utilities between prosumers in an EIP is proposed as a mechanism design to encourage prosumers to participate in trading surpluses. Blockchain transactions and Smart Contracts, combined with Internet of Things (IoTs) technology such as smart meters, are the implementation means to secure that the terms of exchange agreed upon will be automatically enforced. During the simulation of the EIP, each prosumer (represented by a negotiation agent) chooses whether to negotiate with another prosumer or to buy or sell its surpluses to a traditional service provider, such as a main electric power service provider or a gas provider, according to a previously learned policy while considering the context it is immersed in. Utilities between prosumers are exchanged based on a digital currency, the token, which could be readily implemented over Ethereum/Solidity platforms. Smart contract negotiations between prosumers revolve around agreeing (or not) on the price expressed in tokens of a utility profile, given the private and public information available to different parties. Simulation results highlight how automated negotiations allow prosumers to reach higher profits in the P2P Market from trading utility surpluses.

Keywords: Industrial Symbiosis and Internet of Things · Automated Negotiation · Blockchain and Smart Contracts · Game Theory · Reinforcement Learning.

1 Introduction

The distributed co-generation (e.g., heating, cooling, electric power, chilled water, gas), shared storage systems and flexible/distributed demand/supply of intermediate products and waste materials [21] are the distinctive components of

EIPs when compared to regular industrial parks. "Industrial Symbiosis" [5] is the term that best describes EIPs and the way traditionally separate industries collectively take part in a park while exchanging materials, energy, by-products, or even information, based on the synergistic possibilities offered by geographic proximity and interconnectivity, in the individual seek for higher benefits and profits.

In such a setting, each industry in the EIP correspond to a prosumer, that is, a proactive consumer with distributed energy resources (e.g., rooftop solar panels, biogas facilities, cooling towers) [27] that exchanges utilities surpluses or industrial services in a P2P Market with its peers while actively managing its consumption, production and energy storage [20]. A transaction between any of these prosumers, thus, is an agreement to exchange in a P2P manner an amount of a certain utility or industrial service for another or, in this work, for tokens, the digital currency used in the EIP.

The selfish nature of companies is justified at the light of their quest to individually achieve higher profits, many times in disregard of the effects their actions may have over the whole industrial park. In the symbiotic scheme proposed, this typical conflict of interests needs to be resolved in order to avoid the failure of the EIP, as stated in [6] and [30], motivating each partner company to participate in the EIP under the promise and realization of increasing its own profits in a win-win game [17].

In this work, the design of a P2P Market prototype for an EIP, based on a Blockchain approach with a distributed ledger [26] and Smart Contracts [14], is presented. In this prototype, prosumers, represented by negotiation agents, make use of private preferences and public information of the context to decide whether to negotiate in a peer-to-peer way with other prosumers in the EIP and how to conduct such negotiations, or to buy/sell their utility surpluses to main service providers. In order to decide which action to take given preferences and context, agents will resort to a policy previously learned via simulation with Reinforcement Learning [28], while accounting for other peer policies, their models and contextual information they consider. Preliminary promising results are presented as well in an EIP where prosumers negotiate with each other for a single utility, or buy/sell the utility surplus to a main provider.

2 State of the art

In the last few years, the existent literature has made focus over P2P Markets of prosumers producing, consuming and exchanging surpluses of different utilities or services, mainly in electricity markets [3, 13, 20, 33], but also in heat exchange networks in EIPs [21], biogas generation and wastewater treatment plants [10]. Prosumers in these P2P Markets have some advantages over conventional consumers: although they still have goals and interests of their own, collaboration between them emerges through a wealth of cooperating infrastructures [27], producing higher profits and competitive advantage to all participating firms in a win-win collaboration strategy [17].

In spite of the new available technologies and business practices (e.g., greener systems and more collaborative players), the creation and maintenance of a support infrastructure for P2P Markets is a great challenge that must be addressed [23], together with the complexity of balancing power relationships between prosumers to keep the EIP operating [6]. One way to cope with such complexity is the design of prosumer-centric interaction mechanisms where prosumers are incentivized to exchange their utility surpluses without the direct intervention of a central authority [13]; a third party that may eventually override individual preferences, needs and objectives of one or a group of prosumers [19]. Among others, automated negotiations arise as a possible mechanism design for prosumers to resolve the terms under which their utility exchanges will be conducted.

Automated negotiations were addressed from different perspectives in the last few years ([2, 12, 24]). The existing literature has made special focus on the development of strategies for rational agents negotiating in a bilateral (or P2P) type of interaction, where two agents negotiate in a rational way for a number of issues [1, 9]. In this work, issues correspond to exchanges of utilities or industrial services for money in a digital currency. Thus, negotiation agents will try to maximize their profits in the P2P Market of the EIP while reaching the best possible deals during a sequence of negotiation episodes [16]. IoT devices [18], such as smart meters, combined with the decentralization provided by new technologies as DApps and Blockchain [26], guarantee prosumers that terms of utility exchanges agreed on a Smart Contract [14] will be undoubtedly executed. Moreover, the Blockchain technology motivates the participation of prosumers in the EIP as general coordinators are not necessary [33].

Prosumers in an EIP will be represented by negotiation software agents [8]. In order to conduct the mentioned negotiations, agents need to consider some aspects that are unavoidable in real-world interactions. Those are the represented prosumer's private information (preferences and needs) [1], the interactions between prosumers in the EIP (the occasional opponents) [31, 32], and the environment influencing strategic behaviors within P2P Market (the context) [25]. Hence, each software agent need to be of a context-aware nature [15], while also considering its own and its opponent's preferences. The stability of the P2P Market strongly depends on a negotiation infrastructure that helps concerned agents to close exchange contracts (here, automatically) to trade the utility surpluses that may exist [30].

3 Conceptual design of the negotiation infrastructure

In this section, the conceptual design of an automated negotiation infrastructure for Smart Contracts within an EIP is presented. EIPs, according to [6] and [23], are conformed by a number of prosumers. Fig. 1 shows a pictorial representation of an EIP where two prosumers negotiate and exchange different utilities surpluses while using Smart Contracts based on the Blockchain technology, possibly implemented in a private network. On behalf of each prosumer, there exists a negotiation agent per utility type empowered to take actions such as whether to start a negotiation with a given prosumer, to reject the terms in a current negotiation, or to accept an offer. When negotiations reach an agreement, Smart Contracts are signed, an action that will enforce to comply all the terms therein established. Accordingly, the corresponding payment in tokens is made to the prosumer acting as a seller. If the provision service is not completely fulfilled, a refund payment is delivered. Alternatively, prosumers could choose to buy or sell their utility surpluses to main service providers (in this case, to gas or electric power providers).

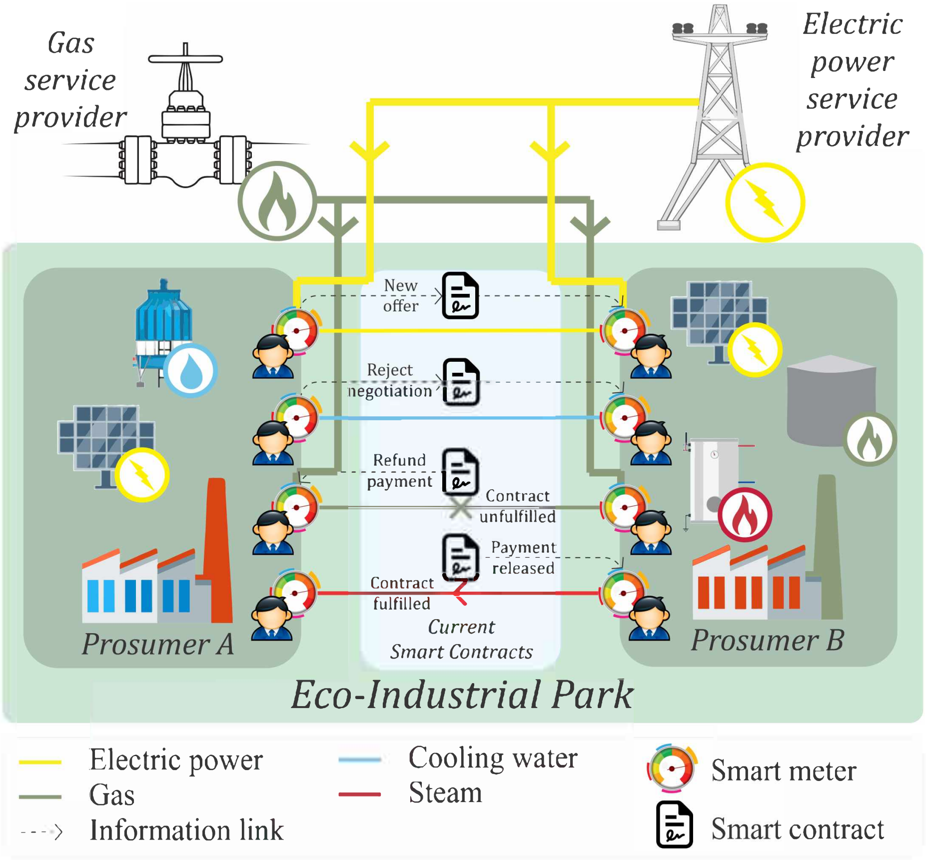


Fig. 1. A pictorial representation of two prosumers in an EIP.

Fig. 2 depicts a representation in SysML [7] of an automated negotiation infrastructure to trade utility surpluses within an EIP. As mentioned earlier, an EIP is made up of prosumers of different utilities and industrial services. Each prosumer in the EIP needs, in its daily operation, different types of utility profiles or workload. In the designed infrastructure, each prosumer is represented by a negotiation (software) agent per utility type (e.g., biogas or electricity). In turn, each agent is equipped with a negotiation policy previously learned using Reinforcement Learning in a simulated environment [15]. The negotiation policy states which action to take at each time step, such as which offer to make in a negotiation episode with other prosumer, whether to start a transaction with an external provider or not, or simply to wait until the next time step.

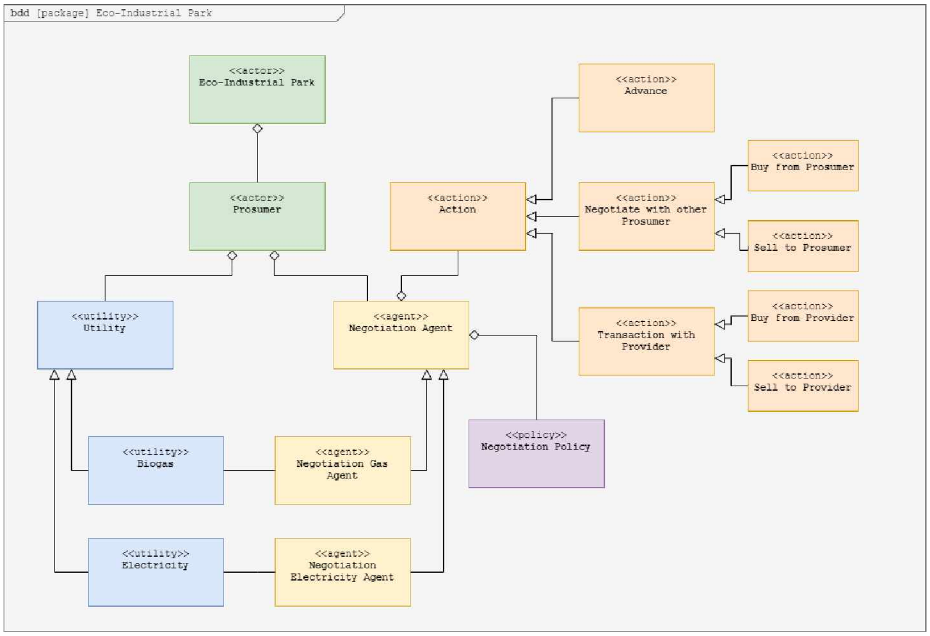


Fig. 2. Block diagram of an automated negotiation infrastructure for an EIP where gas and electricity are the traded utilities.

4 Automated negotiation infrastructure and enabling technologies

One of the problems to implement automated negotiations in peer-to-peer markets is the lack of trust between prosumers. Often, this means that a third party has to participate to certify the rules, terms and the enforcement of the contracts that are signed, a role that is usually played by a coordinator or supervisor agent [13]. Blockchain technology is going to replace this third party altogether. The Blockchain technology was first proposed by the Bitcoin protocol [22]. A Blockchain peer-to-peer system is a network of nodes in which each node keeps a replica of an immutable append-only ledger of transactions. The transactions are issued by nodes called users to exchange information, e.g., to exchange bitcoins in the Bitcoin protocol. The copy of all issued valid transactions are stored locally in the same order in a local ledger by all nodes (replication). The reliability of the replication process is ensured by special nodes called miners that collectively guarantee the integrity of the ledger as a chain of blocks that are interconnected by cryptographic links. Each block is identified by its block header hash which ensures that once the information has been appended to the chain in the form of a block content, it will no longer be modified by anyone in the future without being noticed [11].

Smart Contracts are contracts (or any kind of program) that are converted to deterministic computer code and stored and replicated on Blockchain systems [29]. They are executed exactly in the same way by each node in the Blockchain system. In other words, the function call requests to them are ordered (thanks to the consensus mechanism) and then executed in the same order, sequentially, one request at a time, at all nodes, a process that is also called "active replication" [4].

This section describes the architectural design of the prototype, defining the components of the distributed system, which is made up of the following modules: the Blockchain, the Smart Contract, the negotiation agents and the information dashboard.

4.1 Blockchain

The Blockchain network is a private Ethereum Blockchain-based network. It is composed of an inmutable ledger Blockchain, the smart contract Utility Negotiator, one wallet per prosumer, one wallet per main provider, one wallet for each miner. Each wallet must have a positive balance of tokens (or UtilityTokens), in order to carry out transactions in the Blockchain. The UtilityToken will have a value that can be traded to units of different types of energy, as well as an equivalent amount in physical money, and can be purchased for using the equivalent in utility transactions. Once the Ethereum network has been initialized, Smart Contracts can be created, one for each type of utility within the P2P Market of the EIP.

4.2 Negotiation Agent

The negotiation agent is the authorized agent to provide data to the Blockchain system and interact with it while following the established rules. Negotiation agents will decide to sell their surpluses or to buy depending on their deficits of a certain type of utility. Decisions taken by agents are based on the context information perceived from different sensors, as well as its own preferences, environment models, negotiation policy and learning mechanism, which will allow it to behave strategically while increasing the efficiency of its decisions, ultimately improving the efficiency of the EIP as a whole.

As shown in Fig. 3, agents will check utility surpluses or deficits of the represented prosumer. After perceiving the circumstances of the context, the agent will take an action based on its previously learned negotiation policy. Depending

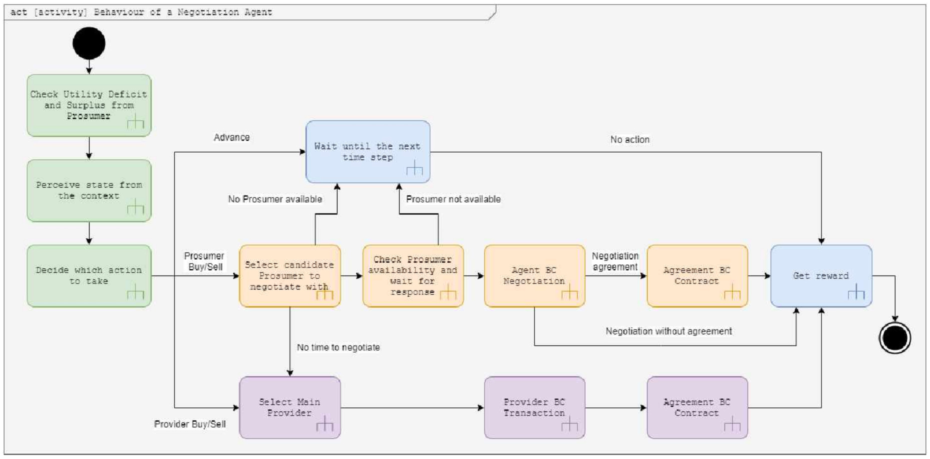


Fig. 3. Activity diagram of a negotiation agent's behavior.

on the action taken by such an agent, a reward signal will hint on the goodness or badness of its decision. The sequence of rewards received by an agent from a sequence of negotiation episodes will be used to learn and adapt its policy.

Available actions, for these negotiation agents, are of three different kinds:

- Wait until the next time step. In this case, the agent does nothing, and just receives the corresponding reward.
- To buy or sell to the main service provider. In this case, the agent selects an amount, provision time, etc., to make a transaction with a provider.
- To negotiate with a prosumer within EIP. In this case, the agent makes use of a negotiation strategy, as presented in [15], while choosing its negotiation parameters depending on the context.

Negotiation strategies for these context-aware agents are defined by a negotiation strategy function σ and its corresponding parameters ψ. The strategy function is defined in Eq. 1, where its parameters ψ will be used by the negotiation agent to compute its next offer O_t to make at each time step t within a negotiation episode.

$$O_t = \sigma(\psi, t) = ip + (rp - ip) * \left(\frac{t}{dl}\right)^{1/cr} \tag{1}$$

As presented in Eq. 1, there are four strategy parameters ψ associated with the agent behavior σ. The parameter ip is the initial price (first offer made by a given agent), rp is the reserve price (last offer the agent deems acceptable), dl is the agent's deadline (last moment at which the agent should close a deal), and cr is the concession rate, namely how the agent increasingly concedes during a negotiation episode.

4.3 Smart Contract

The generic Smart Contract used as the template for all negotiations will be UtilityNegotiator. This contract template can be instantiated by each negotiation agent at any time, and will have full visibility so that any other prosumer agent of the same type of utility can be aware of it. It will have an initial instance, in which the agent makes a request to negotiate. It will have a later instance, where it receives the will to negotiate from a second agent. The third part is the negotiation process itself, which is a cycle of offers/counteroffers that can end anywhere. If the negotiation ends successfully, an utility supply contract will be generated in which all the conditions and requirements will be established, as well as the moment in which the provision will be actually made. As each type of utility has its particular conditions, in reality, a Smart Contract will be available for each type of utility traded, but its processing logic will be similar. A sequence diagram of a prosumer trying to buy a certain amount of utility is shown in Fig. 4.

4.4 Information Dashboard

To provide useful information to prosumers in the EIP, there is a web application in which it will be displayed in real time:

- The transactions resulting from signed Smart Contracts.
- The volume of utility traded, both within the EIP as a whole and by each prosumer.
- Different statistics and graphs about the P2P Market implemented for the EIP .
- Block explorer to show Blockchain status.
- The schedule of past and active transactions.
- A forecasting tool for each utility internal demand and its overall balance.

4.5 Implementation

As mentioned earlier, the main objective of the proposed Blockchain-based negotiation infrastructure is to provide a secure and transparent market environment for trading utilities using UtilityTokens. The negotiation infrastructure is implemented using the Ethereum/Solidity open source platform. The P2P Market is actually a network of prosumers that allows the definition of Smart Contracts, which are instantiated or created by agents when requesting a utility purchase or sale. The terms and conditions of each contract are the outcome of a successful negotiation between agents from different prosumers of the EIP, or a purchase of the needed utility from the external supplier. However, whatever the case may be, the entire process is reflected in the Smart Contract signed. In addition, each agent has a time-varying number of tokens, that i,s the credit to engage in utility transactions. Regardless the utility being traded, the Utility Token has its corresponding value in the Ether (cryptocurrency of the platform used) unit.

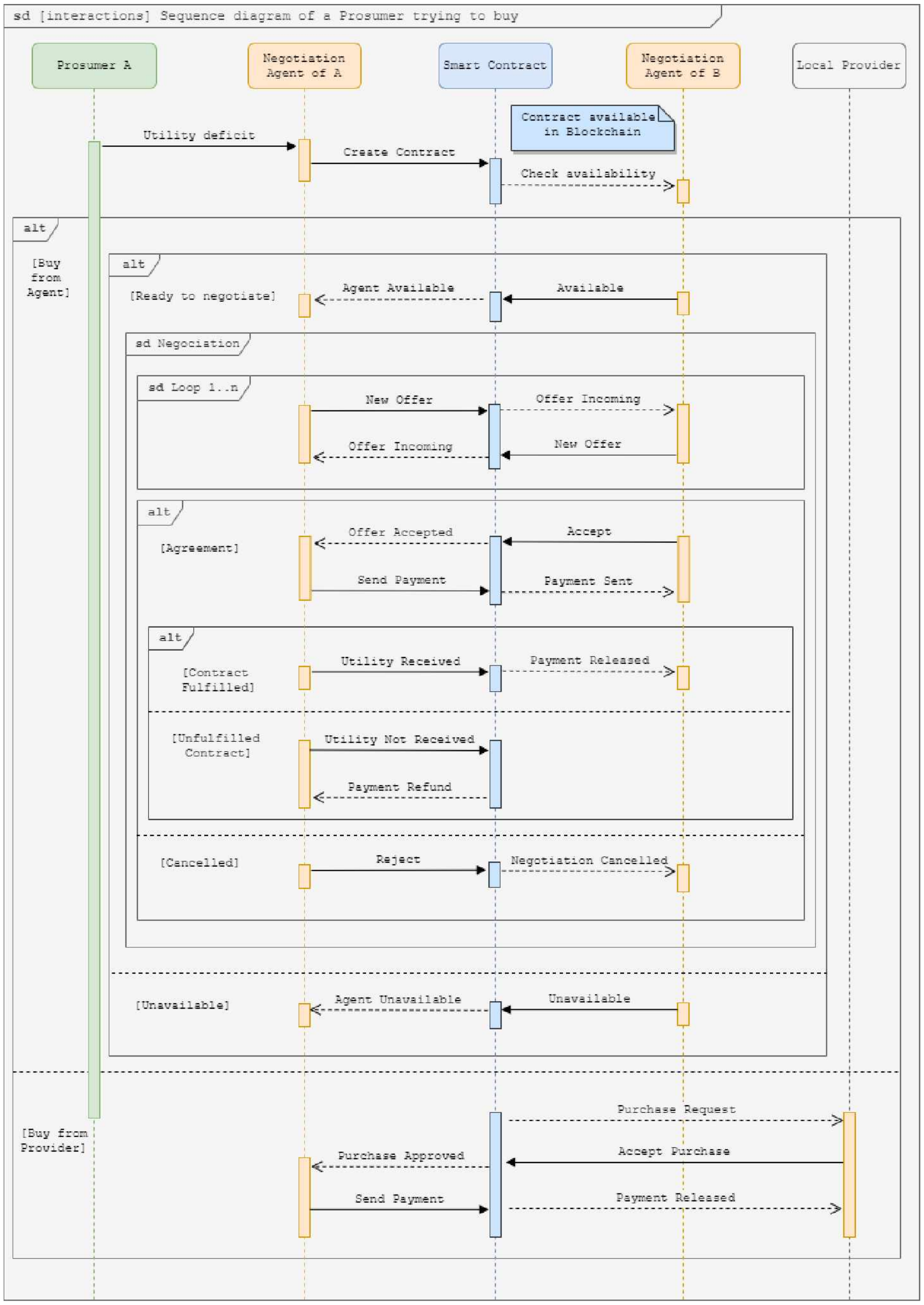


Fig. 4. Sequence diagram of a prosumer trying to buy a certain utility.

To implement the aforementioned utility contract and the associated transfer of tokens, is used the Solidity language, which is object-oriented and considered the today's standard for programming Smart Contracts in Ethereum.

On the other hand, a simple web application is available, where the prosumers can see on a dashboard the information related to each of its agents, detailing the negotiations and closed agreements as a history. In this system, authentication is provided by OAuth 2.0, in order to ensure confidentiality and provide greater security in access to the information corresponding to each prosumer. In addition, for the website front-end, Angular 9 framework, Bootstrap 4 and its corresponding Bootswatch template (Material version) are used. Web services are implemented through Python, which include the management of the information corresponding to the dashboard, and the development of the negotiation strategy of each agent, which stores the intelligence learned during each negotiation episode. To present the information related to the contracts created, the web3.js library is used, as it provides a communication channel with the Ethereum network nodes and allow to extract information from the defined Smart Contracts while using HTTP and IPC connections type. Finally, regarding the data persistence of the utilities and prosumers authentication parameters, a relational database on PostgreSQL is implemented.

5 Preliminary results

In this section, simulation results for utility trading in the P2P Market of an EIP are presented. An interaction between two prosumers in the EIP, simply named as "Prosumer 0" and "Prosumer 1", will be considered as a case study. The Prosumer 0 has a biogas facility with which it generates an amount of biogas on a daily basis. During a particular operational day, its own generation leaves a certain surplus of biogas (here, 100 m^3), that Prosumer 0 stores in a gas holder or tank with a maximum capacity of 200 m^3. On the other side, Prosumer 1 has no such facility, and thus needs to buy gas (here, 150 m^3) from the main service provider or to another prosumer, e.g., Prosumer 0. The price to buy 1 m^3 of gas from the provider is 80 tokens, while the price for selling 1 m^3 of gas to the main provider generates a revenue of 20 tokens.

Fig. 5 depicts the preferences (in a scale from 0 to 1) for both Prosumer 0 and Prosumer 1 regarding the amount of gas they would like to sell or buy, respectively, and at which time step would they consider that exchange most appropriate. As can be seen, for Prosumer 0 preference values are almost the same regardless the moment at which the transaction is made, as long as most of its surplus (100 m^3) is sold to any other prosumer. The situation is a little bit more complicated for Prosumer 1, as it needs a certain amount of gas (probably, the 150 m^3 shown) before its deadline (situated near time step 350) is reached. This deadline may be due to private needs of Prosumer 1, such as processing an incoming rush production order.

As there is a significant difference between the buying price (80 tokens) and selling price (20 tokens) of 1 m^3 of gas to the main provider, prosumers are aware

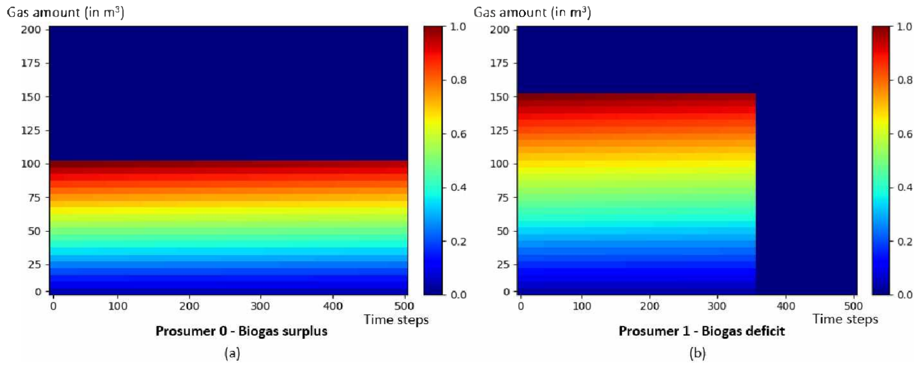


Fig. 5. Prosumer preferences before starting a negotiation

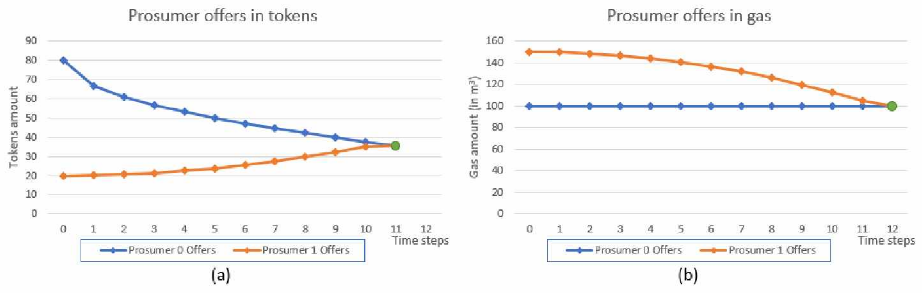
there is enough room to pursue an agreement between them if they negotiate with each other, in a win-win game. Thus, prosumers let their negotiation agents choose the best way to negotiate with each other, which they do by selecting the negotiation parameters to start the negotiation. Which parameter values do negotiation agents select to negotiate depend on the learning previously made, recorded in the negotiation policy, which ultimately relate actions to the state of the context and the private needs of each prosumer.

Table 1. Negotiation parameters selected.

	Negotiation parameters			
	ip	*rp*	*dl*	*cr*
Prosumer 0	80	20	20	2.0
Prosumer 1	20	80	20	0.5

Negotiation parameters selected by Prosumer 0 and Prosumer 1 are presented in Table 1. Prosumer 0 starts the negotiation by setting an initial price *ip* of 80 tokens, the tariff at which the main provider offers gas supply. On the other side, Prosumer 1 chooses the initial price of 20 tokens. Other parameters depend strongly on the influence of the context, private preferences and perceptions of each prosumer. Offers and counteroffers during negotiation are shown in Fig. 6.

During the negotiation episode, agents concede in the way determined by the negotiation policy parameters and the σ function presented in Eq. 1. In Fig. 6 (a), agents concede in the amount of tokens they agree to exchange for 1 m^3 of gas according to the selected negotiation strategy. The same goes for the amount of gas to buy or sell, with a minor difference: Prosumer 0 does not concede, as it assumes Prosumer 1 wants the highest amount of gas it could give, according to previous offers. Agreement is reached in time step 11 for the price in tokens, and in time step 12 for the amount of gas being negotiated.



(a) (b)

Fig. 6. A single negotiation between Prosumer 0 and Prosumer 1. (a) shows the offers made by their agents in tokens to reach an agreement in price, while (b) shows the offers made by their agents in m^3 to reach an agreement in the amount of gas.

In this situation, both prosumers obtain a better deal than what they would have obtained if selling or buying gas dealing with the main provider. On one hand, Prosumer 0 gets 35 tokens per 1 m^3, when it would receive only 20 per 1 m^3. On the other hand, Prosumer 1 pays 35 tokens per 1 m^3 of gas, when it would paid 80 tokens per 1 m^3 if no negotiations with other prosumer were conducted. In this setting, both prosumers get a better deal in the P2P Market through the negotiation mechanism in the EIP.

This negotiation leaves Prosumer 1 with a deficit (smaller, though) of 50 m^3 of gas. This prosumer has room yet to fulfill its needs (deadline is approximately 340 time steps away). Meanwhile, it could negotiate with another prosumer as it has done with Prosumer 0, or buy that deficit to the main service provider of gas. Anyhow, prosumers profit from better deals by trading within the EIP compared with transactions that can be only made with main services providers.

6 Concluding remarks

The design of a P2P Market prototype for the automated negotiation of utilities between prosumers in an EIP was presented. To this end, a conceptual design of a Blockchain-based negotiation infrastructure for a P2P Market within an EIP was discussed, alongside with a brief explanation of which technologies would be used in such a setting and how would they integrate together.

In the scheme proposed by EIPs, prosumers are able to reach higher profits while negotiating with their peers to exchange utility surpluses or industrial services. This Industrial Symbiosis allows the P2P Market to reach higher benefits in the whole, but also allows prosumers to risen their profits individually, in a win-win manner, as shown in Section 5.

Trust issues in the P2P Market of the EIP are resolved by the Blockchain approach presented in this work. In this sense, Smart Contracts assure prosumers, represented by negotiation agents, that every agreement reached during a negotiation is to be executed. Such a trustworthy mechanism rids prosumers of the inconvenience of unveiling their private preferences or needs to a third party or general coordinator of the P2P Market.

Preliminary results highlights that this is a promising area of research. Future work will revolve around how agents could learn negotiation policies that leave the EIP in conditions near to a Nash Equilibrium, the proper identification of prosumer's preferences to negotiate while also considering context circumstances, and the implementation of DApps and how to integrate them tightly with IoT devices as smart meters.

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