LEVERAGING AI TO REVOLUTIONIZE BUSINESS PROCESSES

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Abstract

In an increasingly dynamic and competitive industrial environment, organizations face the challenge of maintaining decision-making autonomy while responding to increasingly complex external demands. This paper proposes an intelligent, agent-based framework to coordinate simultaneous and parallel negotiations among autonomous entities such as microgrids or organizations operating within the same sector competing for access to limited and heterogeneous resources.

The model targets organizations that are unable to independently fulfill large-scale contracts and are therefore compelled to outsource parts of these contracts, sometimes even to competitors. Each organization aims to preserve its autonomy and minimize the disclosure of sensitive business information. In this context, interoperability becomes fragile, requiring constant adjustments that may conflict with existing systems and structures.

To address these challenges, the paper presents a collaborative platform supported by a cloud-based infrastructure and intelligent negotiation mechanisms, where autonomous agents iteratively evaluate and adjust offers and counteroffers. The negotiation process is managed through a communication protocol that ensures transparency, flexibility, and consistency in information exchanges.

By leveraging AI, the proposed system transforms how business processes are managed, delivering key benefits such as decision automation, reduced response time, enhanced collaboration, and increased sustainability within virtual enterprise networks. Negotiation thus becomes the central mechanism through which autonomous organizations reach consensus, align objectives, and co-create value in an integrated digital ecosystem.

Keywords: *AI, negotiation process, MAS, microgrid, smart agents, dynamic environment, Network Enterprises, Virtual Enterprise.*

1. Introduction

In today's highly dynamic and competitive industrial landscape, organizations are under growing pressure to respond rapidly to shifting market demands, evolving regulations, and sustainability imperatives. To remain agile and efficient, enterprises are establishing specialized business units to identify and align with optimal partners and suppliers, thereby ensuring that their offerings meet both operational and strategic objectives. This drive for efficiency, scalability, and responsiveness has increased the need for seamless collaboration, particularly through intelligent and automated negotiation mechanisms.

At the heart of this transformation lies the concept of Enterprise Interoperability[1] (EI), which refers to an enterprise's ability to exchange and understand information effectively, whether internally between departments or externally with partners and third-party systems. While large enterprises often set standards within their supply chains, **Small and Medium Enterprises (SMEs)** are more sensitive to external market fluctuations, requiring them to constantly adapt their systems and practices to maintain interoperability. **Sustainable Enterprise Interoperability (SEI)** further extends this concept, emphasizing the need to preserve interoperability across the entire lifecycle of systems and applications — demanding continuous updates, maintenance, and adaptation[2].

Recent advances in information technology have enabled the formation of **Virtual Enterprises (VEs)** or **Networks of Enterprises** — dynamic alliances of independent organizations that pool resources and expertise to capitalize on business opportunities. These networks are increasingly common in sectors where decentralized

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[1] M.-S. Li, R. Cabral, G. Doumeingts, K. Popplewell, *Enterprise Interoperability Research Roadmap*, no. July. European Commision - CORDIS, p. 45, 2006.

[2] R. Jardim-Goncalves, A. Grilo, C. Agostinho, F. Lampathaki, Y. Charalabidis, *Systematisation of Interoperability Body of Knowledge: the foundation for Enterprise Interoperability as a science*, in Enterprise Information Systems, vol. 6, no. 3, pp. 1-26, 2012.

operations, such as those involving microgrids in the energy domain, require intelligent mechanisms to ensure coordination and efficient resource sharing.

Microgrids, as part of modern smart grid systems, represent a significant breakthrough in decentralized energy management[3]. They are composed of Distributed Energy Resources (DERs) that autonomously manage local generation, distribution, and storage. However, to meet large-scale energy demands or respond to emergencies, microgrids must collaborate. This often necessitates outsourcing parts of their commitments to other microgrids — which may even be competitors. Such interactions demand high levels of interoperability and intelligent negotiation frameworks that preserve each entity's autonomy while enabling cooperation through minimal and controlled information exchange.

To address these challenges, this paper proposes an **intelligent collaborative system** capable of managing **simultaneous, parallel negotiations** in a dynamic, B2B-oriented environment. Each microgrid manager retains full decision-making control over internal resources, contracts, and objectives, while participating in negotiations only to the extent necessary. When a new demand arises, the manager evaluates whether it can be handled locally or must be outsourced. If outsourcing is required, the system facilitates structured negotiations with other microgrids, segmenting the task into manageable parts and initiating parallel discussions. Upon reaching agreement, formal contracts are established.

Unlike traditional negotiation frameworks that may restrict autonomy, the proposed system incorporates **smart coordination services** and **negotiation agents** that mediate the process without overriding local control. Through AI-driven evaluation of offers, counteroffers, and partner capabilities, the system supports effective collaboration while ensuring flexibility and resilience.

This paper introduces a conceptual and architectural foundation for such an AI-enhanced system, detailing the negotiation models, communication protocols, and coordination mechanisms necessary to revolutionize how enterprises — particularly microgrids — operate and interact in a modern digital ecosystem.

The following sections describe the negotiation in Multi-Agent Systems (MAS), the collaborative intelligent architecture, the coordination components that manage different negotiations, and the final considerations of this paper.

2. Negotiation in Multi-Agent Systems

Given the progress of information and communication technologies, most forms of negotiation described in the previous chapter can now be automatically implemented and managed by information systems. Among these technologies, MAS have been the most widely used to implement negotiation processes. Considering that negotiation is one of the most commonly used behaviors when multiple autonomous agents interact, numerous models and negotiation life cycles have been proposed [Robinson and Volkov'98] [Raiffa'82].

Kersten [Kersten et al.'99] identifies two forms of negotiation – integrative and distributive: Distributive or competitive negotiation (win-lose) sees negotiation between two participants as a situation where only one can win. This type of negotiation is based on the use of proposals/counter-proposals to achieve the initial goal. Various auction methods [Sandholm'99], widely used in e-commerce, fall into this category.

In contrast, integrative or cooperative negotiation (win-win) considers the negotiation object as an integral part of the process: the object is constructed by the parties involved and evolves throughout the negotiation. This dynamic construction is based on exchanges of proposals (offers) that participants build on previous ones. The approach aims mainly at improving proposals and increasing the likelihood of reaching a consensus. Such negotiations may involve argumentation-based negotiation [Parsons'98] or exchanges of positive or negative responses to proposals [Cordoso and Oliveira'00].

All these types of negotiations, regardless of the category, share common dimensions and characteristics. In this chapter, we aim to structure these features according to the three axes: participant, context, and mechanism. The difference is that the participant is no longer a human being but an information agent[4].

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[3] W. Wang, Y. Xu, M. Khanna, *A survey on the communication architectures in smart grid*, in Computer Networks, vol. 55, no. 15, 27 October 2011, pp. 3604-3629.

[4] P. Tolchinsky, S. Modgil, K. Atkinson, P. McBurney, U. Cortes, *Deliberation dialogues for reasoning about safety critical actions. Autonomous Agents and Multi-Agent Systems*, vol. 25, no. 2, pp. 209-259, 2012.

2.1. Types of Agents Involved in a Negotiation

In multi-agent system (MAS) theory, an autonomous agent is also a cognitive entity. This means that the agent is not only in continuous interaction with the environment in which it is situated, but also lives in a multi-agent world and interacts with other agents. Based on this idea, Wooldridge and Jennings [Wooldridge and Jennings'95] define an agent not only by its interaction with the environment and its autonomous goal-driven behavior, but also by its social capabilities. Agents are aware of the existence of other agents and interact through a specific communication language and interaction protocol.

Starting from this general definition of an agent, the following two dimensions will be addressed:

- the individual dimension, where various types of agents and their characteristics as negotiation participants will be identified;
- the social dimension, where the aspects considered by multi-agent systems when implementing a negotiation process will be analyzed.

2.1.1. The Individual Dimension of Negotiating Agents

The above definition and characteristics form a common foundation for all autonomous agents. However, depending on their behavior, agents can be grouped into three types: deliberative, reactive, and hybrid.

Deliberative agents or „rational agents" behave similarly to humans. These agents possess a symbolic world model that they themselves build and inhabit. They also have mental mechanisms that allow them to make inferences about this world in order to decide on their actions [Wooldridge and Jennings'95].

Reactive agents exhibit basic behaviors that enable them to react to changes in their environment. Operating with simple reasoning, this type of agent relies solely on its perceptions of the external world. The major difference between deliberative and reactive agents is that deliberative agents construct and maintain an internal world model, while reactive agents act based on their immediate perception of the environment — because „the world is the only and best model" [Brooks'86].

Hybrid agents attempt to combine the strengths of both types. The fundamental idea is to integrate fast, simple inferences with some form of deliberative control [Muller'96].

From a negotiation process perspective[5], parties must be capable of reacting to changes and also of anticipating them. This implies that agents need to reason about different solutions in order to continue negotiating. They must also be able to communicate their preferences to evaluate and choose between alternatives. Therefore, deliberative agents are the most suited for this type of process.

Modeling the negotiation process with deliberative agents aims to simulate human negotiation. To negotiate, agents possess knowledge about products and relevant attributes, as well as the values attributed to them by others. This information is used continuously to evaluate previous proposals and to construct new ones. These reasoning mechanisms are modeled through negotiation strategies applied throughout the negotiation process [Lomuscio et al.'01].

2.1.2. The Social Dimension in Multi-Agent Negotiation Systems

As in the multidisciplinary approach to negotiation, the social dimension in MAS defines specific roles for negotiation participants. These roles depend on the selected negotiation model and set constraints on participant behavior during the negotiation to ensure adherence to the intended model.

There is a strong similarity between the roles found in human negotiations and those modeled by agents. In MAS, the negotiation roles mirror those in real-life negotiations and impose similar constraints: seller/buyer, initiator/invitee, and mediator/active participant. Since MAS-modeled negotiation is often implemented within e-commerce infrastructures, the most common roles are buyer and seller.

While the types of roles are similar, the number of participants involved at the same time differs significantly between traditional and MAS approaches. In face-to-face negotiations, the number of participants is usually limited. However, with the use of information infrastructure and the Internet, the number of participants in a single negotiation can increase substantially. Therefore, the number of participants is not fixed and depends only on computational capabilities and the system's response time.

[5] K. Fujita, *Automated Negotiating Agent with Strategy Adaptation for Multi-times Negotiations*, chapter in *Recent Advances in Agent-based Complex Automated Negotiation*, Studies in Computational Intelligence, vol. 638, pp. 21-37, 2016.

Depending on the number of participants, different types of negotiation can be distinguished:

- *Bilateral negotiation*: This refers to negotiations between two individuals prepared to exchange offers on an item they value differently (*e.g.*, each participant has a different price for the same object).
- *One-to-many negotiation:* Typically involves a series of interactions between a seller (or buyer) and multiple buyers (or sellers). Beyond the constraints imposed by roles, the negotiating agent holds a decisive power and influence, due to its global knowledge of the negotiation and the fact that other agents often compete rather than collaborate.
- *Many-to-many negotiation:* Generally, involves broadcast-style interactions. In this case, agents typically have the same role, and the negotiation concludes only if all parties agree on the result.
- *Negotiation as a set of bilateral negotiations:* This type resembles one-to-many negotiation, but interactions happen in pairs, creating several bilateral negotiations. Agents in these negotiations can have very different and well-defined roles. Furthermore, dependencies exist between negotiations, meaning the outcome of one may affect the others. This model is commonly used in business-to-business (B2B) e-commerce, where offers are tailored based on the partner's profile.

Thus, unlike human negotiation, in multi-agent negotiation, both the rationality of the agent and the number of agents are crucial. These dimensions increase the number of interactions and thus influence the system's efficiency.

2.2. The Context of Multi-Agent Negotiation

The context of Multi-Agent Negotiation will be analyzed based on three dimensions: culture, power, and time. Very few studies address how these three dimensions influence the negotiation process.

2.2.1. The Influence of Culture on Multi-Agent Negotiations

The works of Kersten [Kersten and Noronha'97; Kersten and Noronha'98] examine the impact of culture on the negotiation process and the characteristics of intercultural negotiation. Several cultural aspects are identified, but three are especially important for modeling negotiation processes in information systems:

- *Individualism/collectivism:* In collectivist cultures, an individual's goals are embedded in the group's goals. In contrast, in individualist cultures, personal goals are clearly separated from group goals.
- *Status:* Some cultures impose strong restrictions on communication between individuals of different social status, while others have weaker constraints.
- *Time:* Cultures may be monochronic or polychronic in how they perceive and manage time.

In [Kersten et al.'97], the Inspire system is used to conduct and model the negotiation process, in order to analyze negotiations involving participants from different countries and cultures. The results confirm not only that „culture influences negotiation through its effects on communication" [E. Wertheim], but also that these influences are substantial. Thus, electronic negotiations are not immune to cultural influences. Culture primarily affects human participants' expectations and behaviors, which in turn constrain the communication and computing mechanisms used in the system.

Other findings are even more surprising: in face-to-face negotiations, participants can adapt their behavior based on perceptions of others' cultural backgrounds. However, in anonymous electronic negotiations, participants lack such cues, and their behaviors are not influenced by other participants' cultures[6].

Cultural influence is seen not only in participants' expectations but also in how the negotiation process is managed and in the negotiation strategies themselves. For example:

In some systems, negotiation starts with the most important attributes and ends with less important ones.

In others, it begins with a general agreement, with key attributes discussed later.

Strategy-wise, some approaches begin with extreme, hard-to-accept offers, while others start with easily accepted proposals.

Strategies for continuing the negotiation can also be classified as flexible or rigid, depending on how much offers change over time [Calantone et al.'98]. Therefore, culture influences not only face-to-face human negotiations but also the information systems used for electronic negotiation.

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[6] R. Caillere, S. Arib, S. Aknine, C. Berdier, *A Multiagent Multilateral Negotiation Protocol for Joint Decision-Making*, chapter in *Recent Advances in Agent-based Complex Automated Negotiation*, Studies in Computational Intelligence, vol. 638, pp. 71-88, 2016.

2.2.2. Power as a Relative Measure of Influence Between Agents

The concept of power in multi-agent systems is often associated with the authority of one agent over another or over a group of agents [Santos et al.'97; Santos and Carmo'96; Governatori et al.'02]. In studies concerning organization within MAS, authority is a concept tied to an agent's role. This means that a role does not merely define interaction processes and communication constraints, but also establishes authority relationships between agents. Authority allows one agent to command or direct another.

In MAS that implement negotiation processes, power can also be identified with the information an agent possesses about the intentions and preferences of other parties [Jones'03]. This information can be used at any time to guide the choice of negotiation strategy [Lomuscio et al.'01]. Thus, the notion of power shifts from being an abstract concept in the multidisciplinary approach to a measurable dimension in MAS, allowing for concrete characterization of the negotiation process.

2.2.3. Time as a Measure of Interaction in Multi-Agent Systems

In addition to the cultural characteristics mentioned earlier, time is frequently used in multi-agent systems that model negotiation to impose temporal constraints on the communication and decision-making mechanisms involved in the process.

Time can be perceived in two distinct ways depending on the negotiation scenario [Krauss'01]:

In a symmetric scenario, time is seen by all participants as a constraint on completing the negotiation process, with everyone aiming to reach an agreement as quickly as possible.

In an asymmetric scenario, time benefits only one of the parties involved. Depending on the context, different communication and decision mechanisms can be employed.

One approach is to parameterize the negotiation protocol directly based on time constraints. These constraints may determine what types of messages an agent can or cannot send at a given time.

Time can also influence the reasoning used during negotiation. Strategies may be selected according to time [Faratin'00; Faratin et al.'98]. Using these strategies, agents generate proposals and counterproposals based on the remaining time interval before a predefined deadline.

Finally, time can be added to the notions of commitment and pre-commitment that occur at the end of a negotiation [Fornara and Colombetti'02]. The constraints resulting from a negotiation can have a temporal status, limiting their validity over time.

Thus, time is used to define:

- the negotiation object;
- the negotiation protocol;
- the negotiation strategy.

2.3. Multi-Agent Negotiation Mechanism

While the dimensions characterizing negotiation mechanisms in informatics resemble those in the multidisciplinary approach, their implementation is quite specific — tied to how MAS execute the negotiation lifecycle.

Compared to the two phases defined in traditional negotiation (*i.e.*, pre-negotiation and negotiation), the lifecycle implemented by MAS consists of:

- identifying potential participants;
- negotiating the terms of exchange;
- executing the transaction [Mullen and Wellman'98].

The first stage is mainly influenced by the number of active participants in a negotiation. It is often implemented by MAS that model marketplaces using brokering systems [Strobel and Stolze'01], where agents meet to participate in one-to-many or many-to-many negotiations. In bilateral or multi-bilateral negotiations, more precise selection of partners is required to identify the most suitable ones[7]. This selection is done by the agents themselves based on their internal representation of potential partners [Faratin'00].

[7] R. Lin, S. Kraus, *Can Automated Agents Proficiently Negotiate with Humans*, Communic. of the ACM, vol. 53/1, pp. 78-88, 2010.

The second stage is more complex, influenced by both the number of participants and the structure of the negotiation object. Depending on the negotiation type:

- In bilateral negotiation, complexity depends primarily on the structure of the negotiation object. Some systems include an arbitrator to determine the optimal solution [Strobel'00], while others model the process as a sequential game involving proposals and counterproposals [Pruitt'75; Jennings'98].
- In one-to-many negotiation, often seen in auctions (*e.g.*, eBay), the model is influenced by the number of participants and object complexity. Auctions require a central institution to coordinate interactions with strict rules ensuring fairness [Sycara'91]. However, the initiator agent may simulate the behavior of such an authority, gaining significant influence over the others.
- In a set of bilateral negotiations, the complexity comes not from the number of participants but from the number of interactions and dependencies between them. These sets are designed to allow multiple bilateral negotiations to evolve in parallel.
- In many-to-many negotiation, the complexity is maximal. To ensure an acceptable level of efficiency, the communication protocols used are typically rigid and heavy, guaranteeing that all participants are involved and agree with the final proposal. This model is found in systems using double auctions (where an agent can be both buyer and seller [Wurman *et al.*'98]) or coalitions with voting-based negotiation [Tsvetovat *et al.*'00].

The final stage of the negotiation process relates to contract theory, focusing on bilateral relationships where parties must fulfill obligations despite external uncertainties.

Thus, the MAS-implemented negotiation process is highly complex and manifests through mechanisms like:

- negotiation object;
- negotiation protocol;
- negotiation strategy.

2.3.1. Negotiation Object

In line with the characteristics of the multidisciplinary approach to negotiation, a large body of computer science research focuses on the structuring of information manipulated during a negotiation — particularly on the description of the negotiation object.

In informatics, the negotiation object represents the attributes around which agreements must be reached.

Depending on the number and nature of these attributes, the negotiation object can be:

Single attribute: The object includes only one attribute — usually the price [Maes and Chaves'96]. It may also be a generic object encompassing multiple fixed-value attributes that are not negotiable, such as available resources or pre-assigned tasks [Mailler *et al.*'01].

Multiple independent attributes: The object comprises several independent attributes like price, delivery time, quality, penalties, etc. Negotiation can target all or only some attributes at a time [Jennings'93]. Agreements on certain attributes do not affect negotiations on the others.

Multiple interdependent attributes: The object still contains several attributes, but they are interdependent. In this case, the process must manage dependencies between attributes [Fatima et al.'04]. Such negotiations are often modeled as constraint satisfaction problems with shared knowledge or customizable dependencies for each partner [Oliveira'01].

The negotiation object can be viewed as a data structure that defines the goals of the negotiation for one or more agents. According to Jennings' approach [Jennings'93], when the object is described by multiple attributes, it defines a negotiation space containing potentially infinite solutions. The purpose of negotiation is to reduce this space to a finite number of solutions — ideally a single mutually acceptable solution.

At the start of the negotiation, the object is described by its attributes, sometimes with initial values. As the negotiation progresses, proposals and counterproposals are instantiations of the object, assigning values to its attributes.

There are three levels of flexibility:

- At its simplest, an agent makes a fixed proposal with set attribute values, which others may accept or reject.
- A more flexible setup allows agents to respond with new offers using the same attributes but with different values.
- Finally, the negotiation process can include dynamic changes to the object's structure — adding or removing attributes. These changes are usually dictated by the negotiation protocol rather than the object itself.

2.3.2. Negotiation Protocol

A negotiation protocol is a formal model, typically defined as a set of rules that governs the negotiation process. As in the multidisciplinary approach, the rules imposed by a protocol cover most negotiation characteristics, such as:

- The roles of the participating agents (*e.g.*, whether the agent is a participant or mediator, seller or buyer, initiator or invitee);
- The various states of the negotiation (*e.g.*, proposal acceptance or end of negotiation);
- The events that can trigger transitions from one state to another (*e.g.*, sending a new proposal or accepting one);
- The actions each participant may take at any given time (*e.g.*, who can send a message, to whom, and when).

To meet user expectations, a negotiation protocol must satisfy several criteria [Krause'95]:

- *Distributed:* The protocol must be decentralized, with no central authority or agent controlling the negotiation;
- *Immediate:* Conflicts should be resolved within a finite and reasonable time;
- *Efficient:* The negotiation outcome (agreement) must be mutually selected and efficient — ideally a Pareto-optimal solution or close to it;
- *Simple:* The protocol must be straightforward and effective, requiring a limited number of messages and system resources (*e.g.*, processor power, network bandwidth);
- *Symmetric:* The mechanism must treat all agents equally — no agent should have a built-in advantage. Swapping identical agents should not affect the outcome;
- *Stable:* The protocol must allow for multiple equilibrium points reachable through simple strategies. A „simple strategy" means one that is understandable and executable in a reasonable time by an agent.

Some of these characteristics are considered natural, inherited from general negotiation properties (distributed, immediate, efficient, stable). Negotiation is, by definition, a distributed process where each party evaluates information from its own perspective to reach a mutually accepted agreement in a fixed time.

However, the notion of simplicity is more debatable. Basic negotiations — like take-it-or-leave-it offers, voting systems, or simple auctions (*e.g.*, eBay) — can be handled by simple protocols. But in complex negotiations, such as double auctions, combinatorial auctions, multi-level or multi-attribute negotiations, or argumentation-based negotiation, simple protocols are often inadequate.

To address the limitations of simple protocols, three main approaches have been explored:

Combining simple protocols: Protocols are treated as state machines, and transitions between them are modeled as actions [Vitteau and Huget'03].

Emphasizing negotiation states over communicative acts: Transitions are governed by the commitments created or altered by actions [Chang and Woo'94; Fornara and Colombetti'03].

Layering additional interaction rules on top of basic protocols based on problem type (see section 4.2).

Additionally, symmetry in a negotiation protocol is more than a byproduct of electronic negotiation. Protocols operate without knowledge of agents' internal characteristics. Roles (*e.g.*, buyer, seller) — not internal features — determine what actions each agent can take.

Protocols are also chosen based on other negotiation dimensions such as:

- number of participants;
- number and nature of the negotiation object's attributes.

Thus, protocol choice impacts not only communication but also the strategies agents adopt — a topic we will now explore.

2.3.3. Negotiation Strategy

During a negotiation, an agent must make various decisions:

- to construct new proposals;
- to evaluate incoming proposals;
- to accept offers at the right time;
- to terminate the negotiation appropriately.

Therefore, the agent requires a reasoning module that helps it achieve its objective(s).

This reasoning module uses negotiation strategies to structure and mathematically characterize the agent's behavior during negotiation. The complexity of this decision-making model depends on:

- the negotiation protocol;
- the nature of the negotiation object;
- the range of possible actions [Jennings'91].

As detailed in the multidisciplinary approach, modern negotiation theory is based on the idea that negotiation is a zero-sum or non-zero-sum game. The art of negotiation lies in getting the counterpart to make concessions on key issues (*e.g.*, price), or to find alternative arrangements that benefit one party without significantly disadvantaging the other.

Because such problems have been extensively studied in game theory, with highly developed mathematical tools, many negotiation strategies in MAS derive from this approach.

In game theory, the negotiation mechanism involves choosing a strategy — a decision made by each participant based on predictions about others' actions (cooperative vs. non-cooperative games). Instead of choosing actions one by one, a participant may predefine its moves for every possible situation — this set of instructions is the strategy.

Each strategy yields a certain payoff, and the aim is to find the optimal strategy for each participant. The payoff value depends not just on one's own strategy, but also on the strategies of others.

However, this approach has limitations:

- Utility functions may be difficult to define precisely.
- Participants may have different objectives or incomplete information.
- The computational cost increases combinatorially with the number of agents [Sandholm'99].

Therefore, this method isn't ideal for environments where the participants manage private information (*e.g.*, evaluation criteria or utility functions), or where reaction time is limited, making full planning impractical.

2.3.4. Alternative Approaches

By preserving the game theory framework but raising the abstraction level, other models have emerged. In this view, negotiation between agents is seen as a game governed by the negotiation protocol's rules. This is especially common in electronic markets, which rely on auction-based protocols to manage negotiation.

In classic auctions, a seller tries to obtain the highest price from a group of buyers, each of whom seeks to buy at the lowest price. This model works well for B2C (Business to Consumer) interactions. Common examples include electronic catalogs and online sales platforms like eBay [Maes and Chaves'96].

This type of interaction is modeled as a sequence of offers and counter-offers, under the assumptions that: all participants have fixed and known utility functions, a stable negotiation zone exists.

But in B2B (Business to Business) negotiations, where: entities are autonomous, the negotiation object is often a task to be performed [Oliveira'01], partners may change during negotiation, the protocol is more complex [Kumar *et al.*'02], and the environment is dynamic and open, the strategy must adapt dynamically to changing conditions, and handle multiple utility functions rather than maximizing a single one.

A negotiation strategy becomes a composition of multiple tactics, each based on different parameters. Faratin [Faratin'98] proposed three such tactics:

- *Resource-based tactic:* Offers are generated according to the amount of available resources;
- *Time-based tactic:* Offers are generated based on negotiation duration and deadlines;
- *Behavior-based tactic:* The agent imitates the opponent's behavior based on their previous offers.

Faratin's model is designed for two-agent scenarios. In settings with more than two participants, coalitions may form [Newmann *et al.*'44; Bergstresser and Yu'77]. These coalitions reduce the number of negotiation participants. However, implementing coalitions raises issues:

- How are coalitions formed?
- How is the profit distributed among coalition members?

In conclusion, negotiation strategies are highly dependent on:

- The number of participants;
- The negotiation context (*e.g.*, time and culture);
- The negotiation object;
- The protocol used.

Designing an effective negotiation system requires accounting for all these dimensions — and the dependencies between them.

3. Architecture and Coordination Mechanisms for Intelligent Negotiation in Virtual Enterprises

In response to the increasing complexity of business processes in dynamic environments, this chapter introduces a multi-layered architecture and coordination model for managing intelligent, concurrent negotiations among autonomous partners in Virtual Enterprises (VEs). The proposed system leverages artificial intelligence to facilitate scalable, flexible, and autonomous negotiation workflows, preserving decision-making independence while enabling seamless interoperability.

3.1. Coordination Approach: Strategic and Generic Layers

Our approach to negotiation coordination is grounded in two distinct but complementary layers:

- Strategic coordination, governed at the agent level, focuses on individual decision-making and negotiation management.
- Generic coordination, managed at the middleware level, ensures synchronization, message routing, and consistency across all interactions.

This dual structure enables the creation of a multi-agent negotiation system built on a distributed, competitive architecture. The negotiation process is decomposed into three primary sub-processes:

- *Coordination process:* responsible for global management of dependencies and parallelism across all active negotiations;
- *Decision-making process:* allows each participant to independently define goals, evaluate proposals, and make context-driven choices;
- *Communication process:* ensures efficient message exchange and interaction using structured protocols.

In this model, agents may engage in multiple bilateral negotiations simultaneously—each concerning different tasks and partners. The coordination layer ensures:

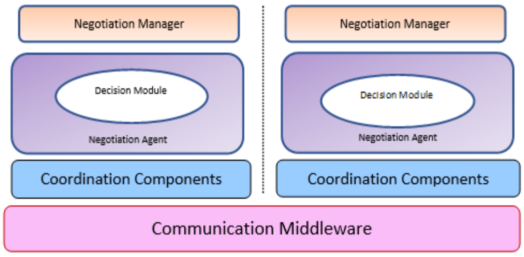
- Integration of multi-phase, multi-attribute negotiations;
- Consistency across multiple engagements by the same agent;
- Logical coherence in decision-making at both local and global levels.

3.2. Intelligent Negotiation System Architecture

To operationalize the negotiation framework, we introduce an architecture composed of four interconnected layers (Figure 1):

- *Negotiation Manager:* responsible for business-level decisions (*e.g.*, initiating/accepting offers, selecting partners, ending negotiations);
- *Negotiation Agent:* assists the manager by handling negotiation states, managing negotiation objects and frameworks, and supporting both global and specific negotiations;
- *Coordination Components:* enforce synchronization rules and manage dependencies across simultaneous negotiations;
- *Communication Middleware:* supports standardized and scalable communication among agents.

Figure 1: The architecture of the collaborative intelligent system



Each negotiation progresses through three stages:

- *Initialization:* defining negotiation objects (single or multi-attribute), selecting participants, and setting frameworks;
- *Refinement:* iterative exchange of proposals/counterproposals aligned with constraints;
- *Closure:* agreement finalization and contract generation.

3.3. Coordination Components and Negotiation Patterns

To support a wide range of negotiation scenarios, we introduce specialized Coordination Components, each modeling a distinct function or constraint:

- *Outsrc/Insrc:* Handle job outsourcing/insourcing via direct exchanges;
- *Block:* Ensures exclusive subcontracting of tasks;
- *Split:* Propagates negotiation constraints across subdivided job slots;
- *Broker:* Facilitates dynamic participant selection;

These components evaluate incoming proposals, ensure compatibility with coordination rules, and generate new offers aligned with global and local constraints. Their modular design supports scalable and reusable negotiation logic.

3.4. Novelty and Advantages

The novelty of this architecture lies in its explicit coordination layer, which enables the simultaneous handling of multiple negotiation threads. In contrast to traditional systems that limit negotiation scope to isolated exchanges, our framework supports:

- Autonomous agent behavior integrated with global coordination;
- Multi-object, multi-attribute negotiation modeling;
- Generic and extensible communication and decision support protocols.

By embedding coordination logic within modular components, this architecture ensures that all negotiation actions—whether local or collaborative—are both coherent and adaptive, even in highly volatile environments.

This chapter lays the foundation for the implementation of an intelligent negotiation system, capable of supporting real-time collaboration across distributed enterprises, and adaptable to future expansions in the digital economy.

4. Collaborative Negotiation Framework for Enterprise Interoperability

In complex and dynamic digital ecosystems, such as VEs, conflicts and disruptions frequently arise due to changes in shared processes, data standards, or strategic decisions. These disruptions pose serious threats to Enterprise Interoperability (EI)—a key requirement for effective collaboration and sustainable performance. This chapter introduces a collaborative negotiation framework designed to resolve such conflicts intelligently and efficiently, using an agent-based approach that aligns with the architecture described in the previous section.

When a change or inconsistency is detected in a network of enterprises, the first step is to identify the interoperability issue. Once the problem is clearly defined, the participating enterprises analyze the impact, evaluate potential resolutions, and initiate a negotiation-based process to reach a mutually acceptable agreement. Unlike unilateral or rigid resolutions, this approach fosters stability and commitment among all involved parties, leading to faster and more sustainable conflict resolution.

4.1. Coordination Requirements for Collaborative Negotiation

Designing and coordinating a distributed negotiation process involves managing several critical factors:

- *Timing:* The negotiation duration is predefined to ensure convergence;
- *Participant set:* Multiple enterprises may engage in simultaneous bilateral negotiations;
- *Negotiation object concurrency:* Bilateral negotiations on the same object require synchronization through coordination policies;
- *Agent-level strategies:* Each enterprise defines decision algorithms and proposal generation strategies;
- *Shared ontology:* A common vocabulary and attribute definition is required to ensure mutual understanding of negotiation terms.

The negotiation process is initiated by one enterprise (E1), which identifies the affected parties (E2...En), defines the Negotiation Object (NO) and Negotiation Framework (NF), and sends the initial proposals. The initiating agent also defines coordination rules to manage proposal generation and acceptance across all negotiations. Each invited participant responds with either acceptance, rejection, or a counterproposal, based on their own NO/NF settings and constraints.

4.2. Agent-Based Negotiation Protocol

To ensure coherence and scalability, negotiations are executed through a multi-agent system. Each agent operates autonomously but adheres to the shared communication and decision protocol. Below is a pseudocode representation of the negotiation coordination logic, implemented by each participating agent:

Pseudocode – Collaborative Agent Negotiation Logic

```
Inputs: Enterprises E1...En; NO (Negotiation Object); NF (Negotiation Framework)
Outputs: Negotiation state: success or failure

BEGIN
on receive start from E1 {
  send initial offer to partner;
}
on receive offer from partner {
  evaluate offer;
  if (offer violates NO/NF constraints) {
    reject offer;
    if (time remains) {
      send counter-offer to partner;
    } else {
      return failure;
    }
  } else {
    forward offer to next partner;
  }
  if (accepted offer received) {
    if (offer accepted in all bilateral negotiations) {
      return success;
    } else {
      if (time allows) {
        send revised offer;
      } else {
        return failure;
      }
    }
  }
```

```
    if (rejected offer received) {
        if (offer is active in other negotiations) {
            return failure in all negotiations;
        }
    }
}
END
```

This approach promotes decentralized control, where each enterprise retains autonomy over its negotiation behavior while respecting the coordination logic required for system-wide coherence. The use of negotiation agents ensures that all decisions are made intelligently, based on local data and strategic intent, yet are aligned with broader interoperability goals.

4.3. Benefits of the Collaborative Framework

The proposed negotiation mechanism brings several key benefits:

- Faster convergence on stable, mutually beneficial solutions;
- Decentralized coordination, enabling scalability across multiple parallel negotiations;
- Preservation of autonomy, allowing enterprises to negotiate selectively and strategically;
- Support for interoperability, even in highly dynamic and heterogeneous environments.

By embedding this framework into the multi-layered intelligent system architecture described in Chapter 3, enterprises can respond to disruptions more effectively, while maintaining sustainable collaboration and operational integrity.

5. Conclusions

In the context of increasingly dynamic and interconnected business environments, particularly in domains such as energy management and manufacturing, the need for intelligent, autonomous coordination mechanisms becomes critical. This paper introduced a smart, agent-based framework designed to revolutionize the way small and medium-sized enterprises (SMEs) engage in collaborative processes, specifically within virtual enterprises such as distributed microgrid alliances.

By leveraging artificial intelligence, the proposed framework enables seamless orchestration of complex business interactions that would be otherwise unmanageable by individual actors. A key innovation lies in its multi-agent architecture that supports simultaneous bilateral negotiations over multi-attribute objects, allowing enterprises to adapt dynamically to contextual changes—such as variations in resource availability or pricing structures.

The architecture is built around a modular three-layer structure:

- The Negotiation Agent layer encapsulates decision-making logic, enabling offer generation, evaluation, and strategy adaptation with optional human-in-the-loop intervention, thus increasing transparency and control;
- The Coordination Components layer handles the synchronization of concurrent negotiations through distributed modules. This decentralized approach enhances scalability and efficiency by allowing multiple negotiations to be evaluated and adjusted simultaneously;
- The Communication Middleware layer ensures robust communication and synchronization across the system, using the Xplore protocol to manage concurrency and negotiation states dynamically.

A notable contribution of this research is the framework's capacity to manage negotiation processes that go beyond simple accept/reject paradigms. The ability to iteratively refine proposals by incorporating new constraints or modifying existing attributes adds significant flexibility, making the system well-suited to the unpredictable nature of real-world business interactions.

Focusing on subcontracting and task delegation within a virtual enterprise of microgrids, the framework illustrates its applicability to a wide range of business domains where agile, distributed coordination is essential. The use case demonstrates how AI-powered agents can collaboratively negotiate, adapt, and execute agreements that align with the overarching enterprise goals.

Looking forward, promising directions for future research include the integration of contract lifecycle management into the negotiation-coordination loop. This would enable automated alignment between negotiation outcomes and the execution of associated business processes. Additionally, developing a user-oriented tool for defining custom negotiation protocols would significantly enhance flexibility, enabling organizations to tailor coordination rules to their specific operational requirements.

Ultimately, this agent-based negotiation system exemplifies how AI can be leveraged to transform traditional business processes, making them more responsive, adaptive, and capable of navigating the complexities of modern enterprise collaboration.

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