Enhance Equity in Agricultural Economic Interest Groups

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Abstract: In agriculture, several structures are set up as cooperative or economic interest group (EIG). However, these structures have a set of limits such as the access to finance, to national and international markets, etc. In addition, they do not care about gender balance or farmers' vulnerability (climate, education, disability, age, fitness, assets, communication channels, socio-cultural norms, prejudice, ethnicity, etc.). This work provides a Citizen Support and Solidarity (*CSS*) mechanism in a context of self-interested farmers (agents) in unstable and uncertain context (interests, availabilities, interdependencies, etc.) where we consider each EIG or each cooperative as a coalition. *CSS* proposes a core-stable, auto-stabilizing coalition formation mechanism which maximizes social welfare, and converges gradually to near optimal results. *CSS* combines game theory methods and the laws of probability. Our experiments and their analysis demonstrate the efficiency of *CSS*.

1 INTRODUCTION

In Senegal, many social communities are set up as cooperative, economic interest group (EIG), etc. with interdependency that can allow them to access to finance, to national and international markets, etc. Moreover, they do not take into account the gender balance or the farmers' vulnerability (climate, education, disability, age, fitness, assets, communication channels, socio-cultural norms, prejudice, ethnicity, etc.).

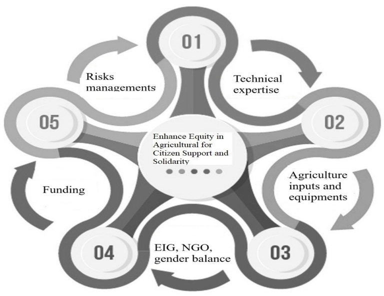

Figure 1: Required supports and ecosystem for farmers.

This suggests new challenges for collaboration between farmers, where we can consider each EIG or a cooperative as a coalition. In game theory, a coalition is typically a set of agents which have decided to join together for a limited period of time, to cooperatively reach a set of goals. In our real world context, an agent can be deployed on a personal device (smartphone, laptop, etc.) of a farmer which must assist through climate information access, financial information, coordination in an EIG (coalitions), etc. The goal of each farmer is to join a coalition that maximises its benefits and minimises the costs incurred or the vulnerabilities. Indeed, different coalition formation mechanisms have been studied, most of them assume that - a stable coalition structure can be computed - the coalition formation process is not interrupted or broken before fitting goals - tasks do not evolve during the coalition's lifetime. In some real-world environments, these assumptions do not hold, for example, when agents face uncertainties about the information they receive or about their dependencies. For example, in an EIG we can have any given structure such as farms' association, non-governmental organization (NGO), a set of singletons (non connected farmer, non associated farmers, a farmer who is not in an EIG, etc.) and farmers with vulnerability factors who can act together in order to establish a cooperation strategy. Thus, a farmer can remain without some useful information or without a teammate to obtain required funding or resource (eligible crops, equip-

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ment of farm production, etc.) and has only a limited knowledge of the distribution of the resources and the available funds.

In this work, the main contribution is to provide a coalition formation mechanism denoted *Citizen Support and Solidarity (CSS)* mechanism in uncertain context (farmers' vulnerabilities, gender balance, resource availability and interdependencies among farmers) which can dynamically form and maintain stable coalitions by:

- managing singletons or vulnerabilities in a decentralized way following the needs of the coalitions;
- organizing the grouping and/or the tutoring of singletons following the needs of the coalition(s) or the equity strategy to form core-stable coalition like in (Faye et al., 2015).
- managing the dynamic merging or splitting of coalitions by allowing the maintenance of the tutelage or to break the tutelage of singletons to form core-stable coalition(s).

CSS mechanism is based on a multilateral negotiation in which control and decision-making are decentralized to enable A-core (Auto-stabilizing Core-stable) coalitions when it is required to deal with the uncertainties. It combines:

1. laws of probability to model the dynamics and unpredictable events;
2. machine learning (ML) algorithms to find the better decision making and similarities;
3. game theory methods to form coalitions.

The remainder of this paper is organized as follows: Section 2 provides an overview of the works in the same field. Section 3 highlights our coalition formation mechanism. Section 4 gives an analysis and performance evaluations of our *CSS* mechanism. Section 5 concludes this study.

2 STATE OF THE ART

In (Zingade et al., 2018), the authors have presented an android based application and an internet site that uses Machine learning methods to predict the foremost profitable crop in the current weather and soil conditions and with current environmental conditions. This system helps the farmers with a sort of option for the crops that will be cultivated, which will be helping them over the long run. Usually, smart agricultural produces enormous quantities of multidimensional time series data and frequent problems with the smart agricultural's IOT devices. In order to solve the issues (Cheng et al., 2022) proposes an anomaly detection model that can handle these multidimensional time series data. In (Faye et al., 2024) authors proposes a model called AIMS (Agricultural Information and Management System) based on some Machine Learning (ML) algorithm which describes both a multi-agent system and Internet Of Things device that ensures data collection and control as well as a data monitoring system via a web platform for decision-making support. This in cases where agents' collaboration are needed for efficient tasks' execution (e. g. data processing and decision making) in a dynamic and uncertain context.

In (Klusch and Gerber, 2002), a dynamic coalition formation mechanism (DCF-A) is proposed, to enable rational agents to react to events which occur dynamically. In DCF-A, each formed coalition is represented by a distinguished agent acting as the coalition leader. The leader examines coalition adjustments by building hypothetical re-configurations and evaluating the risk of adding and removing coalition members. If the leader identifies a significant improvement in coalition value (by simulation), it informs the members about the alternatives. In turn, the agents send their own estimations. Then, the agents and the leader begin a negotiation phase to re-configure the coalition. However, the leaders are sensitive central points and there is no mechanism to manage their unavailability. In addition, the agents in DCF-A are considered not self-interested and always available. Coalition formation in dynamic environments with dynamic tasks are dealt with in (Khan et al., 2011). That work uses MDPs to determine (deterministic) tasks' evolution. However, that study does not consider agent unavailability or the stability of coalitions during tasks' execution. Further, in contrast to our work, it assumes that agents are homogeneous and cooperative.

By using graph theory concepts, (Sless et al., 2014) addresses the problems of computing coalition structures that maximize social welfare, and core-stable coalition structures in situations where the coalitions and their values indicating the strength of relationships between agents is determined by a social network. However, it is assumed that, a central organizer builds coalition structures by using a function mapping agents to their coalitions in order to carry out a given set of tasks. In addition, it is possible for this central organizer to create new relationships between agents to adapt the game and it doesn't require that agents in a coalition form a connected component in the corresponding social network.

In contrast to our work, we aim to set up a coalitions' migration (Citizen Support and Solidarity coalition) mechanism that allows the emergence and maintenance of stable coalitions of self-interested agents in an uncertain context.

3 OUR CONTRIBUTION

3.1 Basic Concepts

To model our context with game theory methods, we assume that, a farmer is an agent. Let $A=\{a_1,...,a_n\}$ be the set of agents and C be a coalition such as $C=\{A_c,G_c,P_c,V_c\}$. $A_c=\{a_1,a_2,...,a_k\}$: $A_c \subset A$ is a set of agents with a set of goals $G_c \subseteq \{G_{a_i}:\ i \in N,\ a_i \in A\}$. P_c is the set of preferences due to agents' vulnerabilities in C and V_c is the expected payoff value with the coalition. $P_c=\{\Theta_{P_c},S_{P_c}\}$, where $\Theta_{P_c}=\{p_1,p_2,...,p_n\}$ comprises one or more preferences p_i and $S_{P_c}=\{S_{t1},S_{t2},...S_{tn}\}$ is the set of preferences' constraints (low,middle or hight).
C receives a payoff value V_c and for each agent a_i to a share v_{a_i} of V_c, where $V_c=\sum_{a_i \in c} v_{a_i}$.

Due to the context with which we deal, each agent is constrained by the parameters: $\{P_{a_i},CDD_{a_i},\vartheta_{a_i},U_{a_i},L_{a_i}^{Net}\}$. P_{a_i} is its preference(s). CDD_{a_i} is its *contract set* which consists of the set of $fixed-term\ contracts$ ($\cup_{j=1}^{|A'|} FTC_{a_i,a_j}\ :\ A' \subseteq A$). A *fixed-term contract* $FTC_{a_i,a_j}=(\{Contract_{a_i,a_j}\},\{T_{help}^{a_i},T_{help}^{a_j}\})$ is a persistent agreement between agents a_i and a_j in which they establish mutual commitment to cooperate with their preferences and share information during a time period. The $fixed-term\ contract$ above specify that, a_i commits a contract $Contract_{a_i,a_j}$ with a_j during a time period $T_{help}^{a_i}$ and a time period $T_{help}^{a_j}$ of a_j. The aim of the *fixed-term contracts* is to facilitate agreements between agents and the stabilisation of the coalitions by taking into account agents' vulnerabilities. The *view* ϑ_{a_i} of an agent a_i is the number of agents of its contact or mailing list (neighbour) with whom it can directly communicate. For example, if $\vartheta_{a_i}=\{(a_j,x_{i,j}),(a_k,x_{i,k})\}$ then a_j and a_k are neighbour agents of a_i. The parameters $x_{i,j}$ and $x_{i,k}$ are boolean parameters which specify, respectively, whether a *fixed-term contract* exists between a_i, a_j ($x_{i,j}$=true) and between a_i, a_k ($x_{i,k}$=true). U_{a_i} is its private utility function. $U_{a_i}=\sum_{c=1}^{\infty} u_c^{a_i}$ where $u_c^{a_i}$ is the utility that a_i tries to maximize through negotiation by participating in coalition C.

$$u_c^{a_i} = v_{a_i} - Cost_c^{a_i} \tag{1}$$

The cost function $Cost_c^{a_i}$ and the payoff v_{a_i} of a_i in C are private knowledge, while for each preference the maximum payoff is a common knowledge. $L_{a_i}^{Net}$ defines its dependence level in a given group (Net).

A *fixed-term contract* is canceled by an agent if the *reliability* of its ally is below some threshold. The *reliability* of a_j is computed by a_i using the *Poisson law* (Yates and Goodman, 2005), which expresses the prior probability of random events over a time interval t. In our case, the random events are the number of times that an agent doesn't respect an established *fixed-term contract*. Thus, the *reliability* of a_j is: $\rho_{a_j}=e^{(-\lambda_{a_j})} * (\frac{(\lambda_{a_j})^k}{k!})$. The agents are self-interested, a_i cannot know the preferences of a_j and must assume a_j prefers staying within *fixed-term contracts*, which implies that the a-prior probability of a_j to break a *fixed-term contract* is 0. Hence, k=0 in the reliability's computation:

$$\rho_{a_j} = e^{(-\lambda_{a_j})} \tag{2}$$

where λ_{a_j} is the withdrawal rate of a_j from FTC_{a_i,a_j} over a time interval t. The withdrawal' threshold W_th depends on the multi-agent application domain. If the number of withdrawal of a_j (NW_{a_j}) from FTC_{a_i,a_j} exceeds W_th, then a_i cancels all *fixed-term contracts* with a_j. Hence, $\lambda_{a_j}=\frac{NW_{a_j}}{W\_th}$. However, a_i doesn't need to store $\lambda_{a_j}\ \forall\ a_j \in A$. Let us consider that, ρ_{a_j}=0.74, then: $e^{(-\lambda_{a_j})}$=0.74 $\Rightarrow$ $\frac{NW_{a_j}}{W\_th}=-ln(0.74) \Rightarrow NW_{a_j}=-ln(0.74)*W\_th$. If a_j does another withdrawal then, $\rho_{a_j}=e^{-(\frac{(-ln(0.74)*W\_th)+1}{W\_th})}$ or if a_j successfully cooperates with a_i then, $\rho_{a_j}=e^{-(\frac{(-ln(0.74)*W\_th)-1}{W\_th})}$. Thus, the relation between ρ_{a_j} and its update ρ'_{a_j} is:

$$\rho'_{a_j} = \begin{cases} e^{\frac{-[(-ln(\rho_{a_j})*W\_th)+1]}{W\_th}} & \text{if } NW_{a_j} = NW_{a_j}+1 \\ e^{\frac{-[(-ln(\rho_{a_j})*W\_th)-1]}{W\_th}} & \text{if } NW_{a_j} = NW_{a_j}-1 \end{cases} \tag{3}$$

Hence, to enhance or conserve its *reliability*, $a_j \in A$ must join and respect its commitments. We identify three *fixed-term contract* properties namely *equitable*, *preferable* and *non-dominated*. A *fixed-term contract* FTC_{a_i,a_j} is *equitable* if it doesn't constrain a_i and a_j, and it enhances the means to both agents.

FTC_{a_i,a_j} does not constrain an agent means: - $P_{a_i} \sim P_{a_j}$ and $T_{help}^{a_i} \sim T_{help}^{a_j}$.
FTC_{a_i,a_j} enhances the means $\forall a_i$ and $a_i \in A$, then:
- $P_{a_i} \sim P_{a_j}$ $\forall P_{a_i}$ and $\forall P_{a_j} \in FTC_{a_i,a_j} \subseteq \cup_{k=1}^{|A'|} FTC_{a_i,a_k}$: $A' \subseteq A$.
-$\forall a_i,a_j$ and $a_k \in A$, $FTC_{a_i,a_j} \cap FTC_{a_i,a_k}=\emptyset$.
The fact that, each FTC_{a_i,a_j} of an agent a_i depends on $T_{help}^{a_j}$, P_{a_j} and ρ_{a_j} of its ally a_j, implies that a_i can have a preference between its allies. a_i may prefer FTC_{a_i,a_j}

over FTC_{a_i,a_k}, e.g., because a_i has more confidence in a_j than in a_k. In such a case FTC_{a_i,a_j} is a *preferable fixed-term contract*. We denote this preferable *fixed-term contract* by: $a_j \succ_{Al} a_k$.

However, a *fixed-term contract* may be equitable but not preferred. Hence, we define the *non-dominated fixed-term contract* as one which is both equitable and preferable.

We consider that, to maximize its utility, each agent a_i has to deal with its dependence level $L^{Net}_{a_i}$ with other agents in a given group (Net). Thus, $\forall a_i \in Net, \exists\ L^{Net}_{a_i}$ such as $L^{Net}_{a_i} = \{\gamma^{Net}_{a_i}, H^{Net}_{a_i}, S^{Net}_{a_i}\}$ where $\gamma^{Net}_{a_i}$ is the set of leader agents of a_i, $H^{Net}_{a_i}$ is the set of agents which have the same importance in Net or just neighbour without relationship with a_i and $S^{Net}_{a_i}$ is the set of agents which have a_i as a leader agent.

In the next section, we present our Citizen Support and Solidarity (CSS) mechanism.

3.2 Citizen Support and Solidarity (CSS) Mechanism

During the asynchronous and decentralized interactions for the CSS, the agents have to deal with uncertainties on their availability, dependence and agreements. An offer from an agent a_i to an agent a_j to join a coalition C of a given structured group Net^A ($a_i \in A$ and $a_j \notin A$) is $Call_{a_i,a_j}$=($P_c, O^{a_i}_c$) which specifies the set of preferences and goals ($O^{a_i}_c$) that a_j is requested to perform in the coalition C (cf. Fig. 2). $O^{a_i}_c$ is a set of compound offer sent by a_i which contains a set of multiple offers for a coalition formation demand. For example, if an agent $a_i \in C$ request from a_j to provide one or both preferences P_1 and P_2, the $O^{a_i}_c$ is seem that:

P_1		P_2	
$\delta_{a_j} < D_c$	$\delta_{a_j} > D_c$	$\delta_{a_j} < D_c$	$\delta_{a_j} > D_c$
$reward_{a_j}$	Val_c	$reward_{a_j}$	Val_c
-	FTC_{a_i,a_j}	-	FTC_{a_i,a_j}
-	$P^{a_j}_s > 0.5$	-	$P^{a_j}_s > 0.5$

$O^{a_i}_c$=($O^{a_i}_{P_1}$,$O^{a_i}_{P_2}$) such as $O^{a_i}_{P_1}$=$\{\delta_{a_j} < D_c, reward_{a_j}, -, -\}, \{\delta_{a_j} > D_c, Val_c, FTC_{a_i,a_j}, P^{a_j}_s > 0.5\}$ and $O^{a_i}_{P_2}$=$\{\delta_{a_j} < D_c, reward_{a_j}, -, -\}, \{\delta_{a_j} > D_c, Val_c, FTC_{a_i,a_j}, P^{a_j}_s > 0.5\}$ Where D_c is the time for the coalition and δ_{a_j} is a_j time spent in the coalition. This means that, if a_j agrees to join C during a remaining time $\delta_{a_j} < D_c$ and to provide the preference $P_1 \subseteq P_{a_j}$ then it obtains only a reward $reward_{a_j}$. Nonetheless, if a_j joins C during a remaining time $\delta_{a_j} > D_c$ then it obtains the maximum reward Val_c and a *fixed-term contract* FTC_{a_i,a_j} if it ensures a probable stability $P^{a_j}_s > 0.5$.

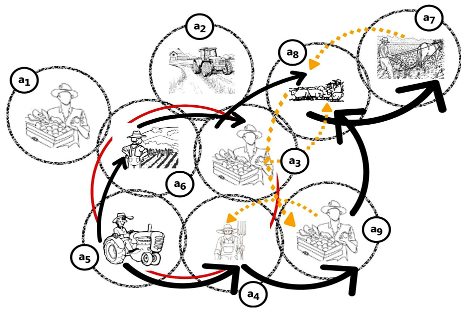

Figure 2: Spread of the offer message $Call_{a_i,a_j}$ by a_5 knowing that A_c=$\{a_3, a_4, a_5, a_6\}$ and local negotiation with singleton of the neighbourhood.

Here, we use compound offers because in our context where we suppose that the agents are spread in electronic devices we try to enhance the sharing information and to reduce the quantity of messages exchanged during the negotiations seen that the sending of messages is more expensive than the mental analysis or oral communication regarding energy used. The second justification is strategic because by spreading out the offers it is easier for the agents to compare their utility between offers and also it allows to reduce the egoism of the agents because the offers are spread out so that if an agent wants to obtain a maximal utility, he has to share information, preferences, and give more guarantee. Also, we allow an agent a_i to propose such compound offer because an agent does not know the utility function and preferences of other agents a_j. An agent a_i may propose a different *fixed-term contract* and reward for each offer in its $O^{a_i}_c$ and for each agent a_j.

An agent a_j has the following utility function which it tries to maximize.

$$u^{a_j}_c = reward_{a_j} - Cost^{a_j}_c \tag{4}$$

We assume that, the cost function $Cost^{a_j}_c$ and the $reward_{a_j}$ of an agent a_j in a coalition C are private information, while the maximum reward after tasks' achievement depending on the preference is a common knowledge. An agent a_j may decide to accept (Accept($Call_{a_i,a_j}$)), counter-propose (Counter($Call_{a_i,a_j}$)), reject (Reject($Call_{a_i,a_j}$)) or ignore a_i's offer ($O^{a_i}_c$).

Alternatively, a_j can counseling a_i (Council(a_i)) on how to modify $O^{a_i}_c$ in order to enhance the ability of a_i to get an agreement with another agent. When accepting or counter offering, an agent must specify an offer (instead of a compound one) from the set of received offers.

For example, in the offer $O^{a_i}_c$ if a_j accept only the constraint of $O^{a_i}_{P_1}$ and has

$P_s^{a_j} > 0.5$ then Accept($Call_{a_i,a_j}$)=($O_{P_1}^{a_i}$,$P_s^{a_j}$). A counter-propose which concerns $O_{P_1}^{a_i}$ is such as Counter($Call_{a_i,a_j}$)=($O_{P_1}^{a_i}$,$P_s^{a_j}$).

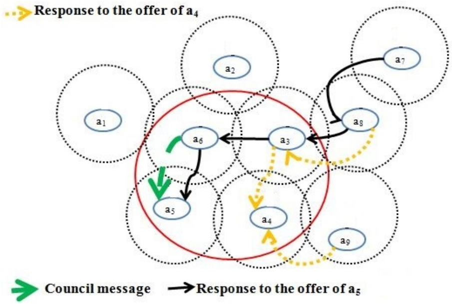

Figure 3: responses to the $Call_{a_i,a_j}$

A Reject($Call_{a_i,a_j}$) means that a_j has the required preference(s) but it refuses the offers because its preference(s) is (are) not available yet or it has a better utility with another agent. As, a rejection of an offer may be due to a bad assessment or ignorance on which offer's constraints may be acceptable for the singleton, a_j can counseling a_i by proposing another $O_c^{a_j}$ to a_i to enhance an offer that does not make an agent in C worse off:

(1) It provides a better utility ($u_{c'}^{a_i} \geq u_c^{a_i}$: C'=$C \cup a_j$) for each $a_i \in C$,

(2) each *fixed-term contract* in $O_c^{a_j}$ is equitable.

(3) a_j can counseling a_i if it exists a *fixed-term contract* between both agents or if it exist an agent a_k which has a *fixed-term contract* with a_i which can grant a_j otherwise a_i ignore the counseling. The formal expression of a counseling is: Council(a_i)=($O_c^{a_j}$,FTC_{a_i,a_j}).

Note that, a singleton a_j can initiate a request for joining a given coalition C. In this case, the singleton a_j must specify the set of preference(s) P_{a_j} it is ready to contribute in C and its probable stability $P_s^{a_j}$. To do that a_j uses the following formal expression: $Recall_{a_j,a_i}$=(P_{a_j},$P_s^{a_j}$). An agent $a_i \in C$ can accept this a_j's request by an acknowledge $Accept(Recall_{a_j,a_i})$=($O_{P_{a_j}}^{a_i}$) in order to highlight the required constraints or refuse a_j's request by an acknowledge $Refuse(Recall_{a_j,a_i})$.

If an agent $a_i \in A_c$ has more than one acceptation, it must follow:

(1) Choose the singleton a_j with the higher probable stability $P_s^{a_j}$.

(2) Choose the singleton a_j which guarantees a higher remain time δ_{a_j}.

(3) Choose the singleton a_j with which it has a previous *fixed-term contract* FTC_{a_i,a_j} and which has the higher reliability ρ_{a_j}.

(4) Choose the first singleton which has accept.

(5) Send a reject (Reject($Call_{a_i,a_j}$)) to the singleton which is not chosen.

These steps are asynchronous because they can be started by each agent. For that, each agent in C has to - check the coalition manageability - synchronize with other agents about its decision - compute its risk to loose its utility with a new coalition configuration. The agents use the probability of ruin ξ_C^t if it remains in C at time t. This ruin occurs if its utility $U_{a_i}^t$ at time t becomes lower than U_{a_i}. We model the cost as X_k. The utility at time t is given by:

$$U_{a_i}^t = U_{a_i} + g^t - \sum_{k=1}^{N_t} X_k \tag{5}$$

U_{a_i} is the initial utility, g^t gain of preferences added since the beginning of the tasks' achievement.N_t is the number of EIG that an agent knows during the time interval [0, t]. The process N_t, $t \geq 0$ is a *Poisson process* with the parameter λ. The ruin probability can be written as follows:

$$\xi_C^t = P(inf_{t \geq 0} U_{a_i}^t \leq 0 / U_{a_i}) \tag{6}$$

Algorithm 1: Ring creation.

Data: A set of linked singletons $S_{a_i}^{Net^{A_c}}$: $a_i \in A_c$
Result: Creation of a ring around the coalition C
$\forall a_j \in A_c$: $P_{a_j} \in P_{min} \subset C$;
if $U_{a_j}^t \geq U_{a_j}$: $a_j \in A_c$ **then**
  if $\exists\, P_{a_j} \equiv P_{a_k}$: $a_k \in S_{a_i}^{Net^{A_c}}$ **then**
    Computes the probability to become unavailable $Q_s^{a_j}$=$(q_s^{a_j})^k * (1 - q_s^{a_j})$;
    Were $q_s^{a_j}$=$e^{-\lambda_{a_j}} * \frac{(\lambda_{a_j})^k}{k!}$;
    if $Q_s^{a_j} \neq 0$ *and* $\delta_{a_j} \leq D_c$ **then**
      Send a message $Request(a_i)$: $a_i \in H_{a_j}^{Net^{A_c}}$ and $a_i \in \gamma_{a_k}^{Net^{A_c}}$
    end
  end
else
  Execute Algorithm 2
end

To avoid risk to loose its utility, an agent must keep the average cost of tasks in terms of preferences used per time unit under a critical threshold p. Thus, if the coalition remains Nash stable (the task(s) is(are) well managed and each agent remains agreed ($U_{a_i}^t \geq U_{a_i}$) with the coalition C) the configuration is committed by an $Syn()$ message. However:

(a) the problem can be only localized in the agent which has requested to link singleton(s). Hence, no synchronizing message is required.

(b) the linked singleton(s) can be shared by the agents of the same coalition for example, if a set of linked

Algorithm 2: Structuring the singletons such as they do not hurt an $a_i \in A_c$.

Data: $U^t_{a_j} \leq U_{a_j} : a_j \in A_c$
Result: Structuring the set of singletons $S^{Net^{A_c}}_{a_i}$
$\forall a_j \in A_c$: $U^t_{a_j} \leq U_{a_j}$;
if $\exists\, S^{Net^{A_c}}_{a_i} : U^t_{a_j} \geq U_{a_j} : a_i$ *and* $a_j \in A_c$ **then**
  Notice($S^{Net^{A_c}}_{a_i}$) and wait during $\varepsilon t \in \mathbb{N}$
end
if *AckNotice*($S^{Net^{A_c}}_{a_i}$) **then**
  Computes $U^t_{a_j}$;
  if $U^t_{a_j} \leq U_{a_j}$ **then**
    Algorithm 4
  end
else
  Algorithm 4
end

Algorithm 3: Auto-grouping the singletons.

Data: Notice($S^{Net^{A_c}}_{a_i}$)
Result: AckNotice($S^{Net^{A_c}}_{a_i}$)
if *Notice*($S^{Net^{A_c}}_{a_i}$) *from* $a_i \in A_c$ **then**
  Each $a_k \in S^{Net^{A_c}}_{a_i}$ compute its probable stability $P^{a_k}_s$;
  Each $a_k \in S^{Net^{A_c}}_{a_i}$ computes its $U^t_{a_k}$;
  Each $a_k \in S^{Net^{A_c}}_{a_i}$ sends $P^{a_k}_s$ and $U^t_{a_k}$ to the $a_i \equiv \gamma^{Net^{A_c}}_{a_k}$;
  a_i sorts its singletons $S^{Net^{A_c}}_{a_i}$ such as the *Designated agent* (*DA*) a_n has ($Max(U^t_{a_n})$, $Max(P^{a_n}_s)$) and the *Backup Designated agent* (*BDA*) a_m has the next ($Max(U^t_{a_m})$, $Max(P^{a_m}_s)$): a_n and $a_m \in S^{Net^{A_c}}_{a_i}$.;
  a_i sends a AckNotice($S^{Net^{A_c}}_{a_i}$) to singleton in $S^{Net^{A_c}}_{a_i}$ and agents in A_c;
end

singletons which have a set of preferences can be needed by a set of agents of the coalition.

If the coalition is not Nash stable due to the fact that an agent a_i of C will get a lower utility or the task(s) is (are) not well managed, then a $Notice()$ message is used by the agents in C. This can lead to one of the following migration of the configuration:
(c) Structuring the singletons such as they do not hurt $a_i \in A_c$ (cf. algorithm 2).
(d) Sub-coalition for the singletons which has the coalition C as a tutor (cf. algorithm 4).
(e) Break the tutoring and create a new coalition formed by former singletons with maybe a set of agents of the former coalition C. However, both coalitions must be stable (cf. algorithm 5).

Algorithm 4: Create a sub-coalition for the singletons which has the coalition C as a tutor.

Data: $U^t_{a_i} \leq U_{a_i} : a_i \in A_c$
Result: sub-coalition (Sub_{A_c}) for singletons $S^{Net^{A_c}}_{a_i}$ which will have C as tutor.
Let us consider that $\bar{A_c}$ is the set of $a_j \in A_c$: $U^t_{a_j} \leq U_{a_j}$;
$a_i \equiv \gamma^{Net^{A_c}}_{a_k}\ \forall\, a_k \in S^{Net^{A_c}}_{a_i}$; a_i send $Probe^{\bar{A_c}}()$ and $Probe^{S^{Net^{A_c}}_{a_i}}()$;
if $Probe^{\bar{A_c}}() == True$ *and* $Probe^{S^{Net^{A_c}}_{a_i}}() == True$ *and* $U^t_{a_i} \leq U_{a_i}$ **then**
  a_i sends a message $Inform(Sub_{A_c})$ which informs the creation of Sub_{A_c}=$\{S^{Net^{A_c}}_{a_i}, Rew_{Sub_{A_c}}, \sum_{j \in S^{Net^{A_c}}_{a_i}} P_{a_j}, (P_{Sub_{A_c}} \in P_c)\}$;
  $\forall a_j \in A_c, a_j \equiv \gamma^{Net^{A_c}}_{a_k} \forall a_k \in Sub_{A_c}$;
  $\forall a_j \in A_c, a_j send(FTC_{a_j,a_k} \forall a_k \in Sub_{A_c}$;
end
if $Probe^{\bar{A_c}}() == True$ *and* $Probe^{S^{Net^{A_c}}_{a_i}}() == False$ *and* $U^t_{a_i} \leq U_{a_i}$ **then**
  a_i demands a grant process ($Grant()$) to motivate $a_k \in S^{Net^{A_c}}_{a_i}$;
else
  a_i demands the creation of a new coalition formed by former singletons with maybe a set of agents of the former coalition C by $Grouping()$ (algorithm 5);
end

A message *AckNotice*($S^{Net^{A_c}}_{a_i}$) means the singletons has already a given structure after the negotiation of their auto-grouping. However, it must be required to break the tutoring and to create a new coalition formed by former singletons with maybe a set of agents of the former coalition C such as both coalitions are stable.
(1) A new coalition where members are the former singletons.
(2) A new coalition which hosts former singletons and a set of agents of the former coalition.

4 ANALYSE AND PERFORMANCES EVALUATIONS

We highlight the properties of *CSS* that lead to required, auto-stabilizing core stable coalitions, the convergence of the negotiations in such dynamic, uncertain and asynchronous context.

Lemma 1. *CSS terminates without deadlock, regardless of the existence of a coalition.*

Algorithm 5: Break the tutoring and create a new coalition formed by former singletons with maybe a set of agents of the former coalition C (*Grouping*()).

Data: $Probe^{\bar{A_c}}()==False$
Result: Creation of a new coalition C' which emerges from C
$\forall\ a_i \equiv \gamma_{a_k}^{Net^{Ac}}$ computes the stability of Sub_{A_c} to form a coalition;
if Sub_{A_c} *will be stable* **then**
  The tutoring is broken and the singletons establish *fixed-term contract* between them;
end
if Sub_{A_c} *will be not stable* **then**
  $a_i \equiv \gamma_{a_k}^{Net^{Ac}}$ computes the stability of Sub_{A_c} if it is in Sub_{A_c};
  if a_i *can stabilize* Sub_{A_c} **then**
    $\forall a_j \in A_c$ computes the stability of the coalition C when $a_i \in A_c$ and when $a_i \notin A_c$;
    if C *remains stable* **then**
      a_i breaks the tutoring and joins the singletons. Then, they establish *fixed-term contract* between them in order to manage in decentralized manner their coalition $Sub_{A_c} \cup a_i$ and to ensure the stability of $Sub_{A_c} \cup a_i$;
    end
  end
end

Proof. $\forall Call_{a_i,a_j}$ of an offer of a_i or $\forall Probe(O_C^{a_i})$ a probe message of a_i, is forwarded if $\vartheta_{a_i}^t \neq \emptyset$ by respecting the *pitch deck* principle to avoid message loop back. Each conflict between a_i and a_j is managed by the rest of the agents of their *network (Net)* by selecting the agent which provides a larger weight to its *network (Net)*. This avoids the case where a_i and a_j are in an impasse without awareness by the agents which are awaiting a commitment. Note that, every conflict resolution is decentralized and localized in the *network (Net)* concerned by the conflict (see in each algorithms). Thus, deadlocks are avoided in the negotiation. This proves our lemma.□ □

Definition 1. *A set of agents A form a Nash-stable partition P, if none of the agents in A is motivated to leave other agents in order to join another partition P' of another set of agents, i.e,* $\neg(\exists\ a_i \in A : a_i \in P, \exists P' : P' \cup \{a_i\} \succ_{a_i} P)$.□

Theorem 1. *An* $AckNotice(S_{a_i}^{Net^{Ac}})$ *entails that there exists a set of agents of a network (Net) which guarantees a Nash-stable partition in C.*

Proof. Consider *W-Set* as the set of agents which responded with an *AckNotice*($S_{a_i}^{Net^{Ac}}$) in a *network (Net)*. Consider that, $U_{a_x}^t$ is the outcome of the utility function U_{a_x} of a_x at time t. Also, consider that W_{a_i} as the weight of a_i depending to its *fixed-term contracts*.
(1) $\forall a_j$, *W-Set*=*W-Set* $\cup\, a_j$ if and only if $G_{a_j} \in O_C^{a_i}$ and $U_{a_j}^{t-1} \leqslant U_{a_j}^t$. This means $\forall a_j \in$ *W-Set* it has agreed to join coalition C in offer $O_C^{a_i}$.
(2) $\forall a_i, a_j \in$ *W-Set*, $G_{a_i} \not\equiv G_{a_j}$, $U_{a_i}^{t-1} \leqslant U_{a_i}^t$ and $U_{a_j}^{t-1} \leqslant U_{a_j}^t$. This means that, there is no conflict between the agents in *W-Set* and each utility is maximized.
(3) $\forall\ W_{a_i}$ of $a_i \in$ *W-Set*, W_{a_i} depends on its *fixed-term contracts* of its view $\vartheta_{a_i}^t$. In addition, a_i aims to maximize its weight and reliability because if it withdraws from *W-Set* its weight and reliability will decrease. (1), (2) and (3) above mean that, $\forall a_i \in$ *W-Set* is not motivated to deviate from *W-Set* and has agreed to join C with each agent in *W-Set*. Thus, *W-Set* $\subseteq C$ is Nash-stable. This proves our lemma.□ □

Lemma 2. *The merging of two W-Set gives also a set of agents which is a Nash-stable partition in C.*

Proof. Consider that W_{a_i} as the weight of a_i depending to its *fixed-term contracts*. Also, consider $X1$ and $X2$ two sets of agents of two different *network (Net)* which responded with an *AckNotice*($S_{a_i}^{Net^{Ac}}$). By theorem 1, $X1$ and $X2$ are both Nash-stables. $X1 \cup X2$ is such that $X1 \cap X2 = \emptyset$. Thus, $X1 \cup X2$ is such that $\forall a_i \in X1 \cup X2$, W_{a_i} and utilities are maximized. Thus, if the merging is a success, each agent maintains its agreement to join coalition C with each agent in $X1 \cup X2$. This proves our theorem.□ □

Definition 2. *Let us consider CS as a coalition structure. CS is in the core of a game if no coalition $C \in CS$ wants to deviate from CS, i.e, each coalition C earns at least as much as it can make on its own (utilitarian social welfare is maximized). This means, C is core stable.*

Theorem 2. *CSS convergences toward a core stable coalitions if the core is not empty.*

Proof. Lemma 1 proves that, if a *AckNotice*($S_{a_i}^{Net^{Ac}}$) exist for a *network (Net)*, *CSS* will take it into account without deadlock. In addition, *CSS* works even if some agents are unavailable, the termination is always guaranteed and each agent has control over the outcome of *CSS* regardless the state of other agents. Theorem 1 implies that, the outcome of *CSS* is always a stable coalition. By lemma 2, if an *AckNotice*($S_{a_i}^{Net^{Ac}}$)

comes from a *network (Net)* or from the merging of a set of *network (Net)* then, no agent is motivated to deviate from the outcome. In addition, the utility, the reliability, the probable stability and the utilitarian social welfare of the set of agents are maximized because the *network (Net)* which provides a larger weight is always preferred. Thus, for each agent's offer, the outcome of *CSS* leads to a coalition where no agent is motivated to deviate and where the utilitarian social welfare is maximized. This proves our theorem.□ □

Lemma 3. *The outcome of CSS is a coalition C where each agent has at least one neighbour agent in C.*

Proof. By theorem 1 an *AckNotice*($S_{a_i}^{Net^{Ac}}$) means that, there exists a set of agents that can form a Nash-stable partition in *C*. By lemma 2, each agent which responds with an *AckNotice*($S_{a_i}^{Net^{Ac}}$) in a *network (Net)* or of the merging of a set of *network (Net)* has at least one neighbor agent with which it accepts to form at least a Nash-stable coalition. Thus, if *C* is committed due to one or a set of *network (Net)*, each agent in *C* has at least one neighbour agent in *C*. This completes the proof.□ □

Theorem 3. *If CSS terminates with a formed coalition, that coalition is necessarily A-core and auto-stabilizing.*

Proof. Theorem 2 proves the convergence toward a core stable coalition. Lemma 3 means that, each event which dynamically affects tasks and agent availability will be detected by at least one agent of the coalition. Lemmas 1 suggests that, after some instability, a coalition will stabilize after a bounded number of steps without a deadlock. In addition, the decision to add a set of agents to the coalition must respect the preference of each agent of the coalition. Knowing that, we can formalize the addition of a set of agents to a coalition as the merging of two *W-Set*, lemma 2 shows that, *CSS* enables dynamic stabilization. This completes the proof.□ □

5 CONCLUSION

In Senegal, the farmers face with the challenges on finance, on markets, on the vulnerability factors with the poor management of the gender balance and the unequal distribution of agriculture inputs. Farmers are grouped together in cooperatives or economic interest groups (EIGs) to address these issues. However, many of them may wish to leave or join these groups depending on the crop year, skills, preferences, or social welfare. This work takes into account this context to provide a coalition's migration mechanism that enables the rising of core-stable, auto-stabilizing and asynchronous coalition formation mechanism which we denote as *CSS* (Citizen Support and Solidarity). *CSS* combines game theory methods and the laws of probability. Our experiments and their analysis demonstrate the efficiency of *CSS*. In the future we aim to analyse the socio-economic impact of *CSS* on local communities by selecting performances metrics and comparison with traditional methods.

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