The Design of Mobility-Aware Tag-Based Cooperation
For Mobile Ad Hoc Networks

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Abstract
This article describes the Mobility-aware Tag-based Cooperation (MaTaCo) approach to cooperation enforcement in mobile environments or MANETs. The MaTaCo approach models individual nodes in mobile environments or MANETs as adaptive tag-based agents capable of adapting their cooperation to changing mobile environment. In contrast to existing work on tag-based cooperation, MaTaCo provides a mobility-aware tag design that incorporates a mobility metric. This allows an agent to measure its tag similarity to its neighbor's based on their relative mobility. Each agent runs the MaTaCo protocol locally which leads to global cooperation enforcement in the network.

Keywords: MANET, nodes cooperation, tag-based cooperation, mobility-aware

Introduction
MaTaCo presents a new approach to the problem of cooperation enforcement in mobile environments or MANETs. It is a tag-based approach that, compared to existing cooperation enforcement models for MANETs, does not require keeping memory of past interactions such as observation logs and reputation records. Hence, it does not need a monitoring mechanism or unique identities that are linked to each observed behavior. We have discussed a number of tag-based approaches for cooperation enforcement in [1]. The approaches have been proved to be capable of promoting high cooperation between agents. However, the approaches are only targeted for stationary agents that have complete view of their environment. Therefore, it is in our interest to investigate how a tag-based approach performs in mobile environments especially MANETs. The mobility of nodes in mobile scenario, each node in the network should be able to communicate with any other nodes in a network, the proposed system should be aware of nodes’ transmission range limit. Any process of the system that involves a pair of nodes should only occur if the pair is within each other’s transmission range.

Requirements
As a consequence to the analysis of existing cooperation enforcement models, requirements are identified that serve as guidelines toward the design of our tag-based cooperation enforcement system. An efficient tag-based cooperation enforcement system for mobile environment or MANETs must address the design requirements simultaneously. The identified requirements are as follows:

1. **R1 Aware of nodes’ transmission range limit.** In MANETs, wireless nodes have limited transmission range. This means that a node could only communicate with other nodes that are within its transmission range. In contrast to existing tag-based approaches which assumes a node can communicate with any other nodes in a network, the proposed system should be aware of nodes’ transmission range limit. Any process of the system that involves a pair of nodes should only occur if the pair is within each other’s transmission range.

2. **R2 Aware of nodes’ mobility.** The mobility of nodes in MANETs creates dynamic environments in which each node’s neighborhood changes frequently. In contrast to existing tag-based approaches which are targeted for wired networks in which nodes are stationary, the proposed system should be aware of nodes’ mobility. It should be responsive and adaptive to changing mobile environment and unable to dictate nodes’ movement simultaneously.

a. **R2a Respond to changing mobile environment.** The system should respond to changing mobile environment in a network such that it maintains the existence of local interaction groups in the network. This means that in any mobile scenario, each node in the network should be able...
to determine whether its neighboring nodes are in the same local interaction group as itself.

b. **R2b Adapt to changing mobile environment.** When the system responds to changing mobile environment, nodes should adapt its behavior according to the response. They should be able to choose the behavior that suits current situation.

c. **R2c Unable to dictate nodes’ movement.** The mobility of nodes is a feature of MANETs and its pattern depend on nodes’ movement. The nodes themselves decide on how they should move in the network. Their mobility is not a feature of the system. Thus, it should not be able to dictate node’s movement.

3. **R3 Ability to form local interaction groups.** Forming local interaction groups in a network is one of the important aspects of tag-based approaches. Based on the principle of tag-based cooperation, the formation of local interaction groups in the network would guarantee nodes to maximize their payoffs provided that they choose to cooperate in their local interaction groups. While existing tag-based approaches have been able to form local interaction groups in stationary environments, the proposed system should be able to form local interaction groups in mobile environments within the constraints of R1 and R2.

4. **R4 Execute algorithm at each node independently.** In self-organized MANETs such as civilian MANETs, each node belongs to a different authority and is independent of each other. Therefore, the proposed system should ensure that the algorithm can be run independently at each node. The independent algorithm execution at each node should lead to global cooperation enforcement in the network.

By satisfying these requirements, the system would be able to utilize nodes’ mobility and limited transmission range characteristics in order to enforce cooperation in mobile environment or MANETs.

**MaTaCo: Mobility-Aware Tag-Based Cooperation**

This section presents MaTaCo approach that satisfies the identified requirements for an efficient tag-based cooperation enforcement system. First, we present the design of agent and interaction components. Then, we describe a distributed tag-based algorithm that utilizes the design of the two components.

**Design:**

This section uses the requirements, **R1, R2, R3 and R4** to derive the design of MaTaCo, a mobility-aware tag-based cooperation approach proposed by this research. The MaTaCo approach’s design is divided into the design of three main components that are complementary i.e. agent, interaction and algorithm components. Figure 1 illustrates the design components of MaTaCo.

![Figure 1: Design components of MaTaCo. The components are divided into agent, interaction and algorithm. Agent component is broken down into tag and strategy components while interaction component is broken down into scenario, payoff and agents reproduction components.](image)

**Agent**

The design of agent component is further divided into tag and strategy designs which are described in detail in this section.

**Tag:**

A tag is an individual trait and observable by others. It should have the ability to structure a population into local interaction groups. In our approach, we incorporate the mobility metric proposed by [2] in the tag design. In their mobility metric, they use the received signal strength which is the power level, $RxPr$, detected at the receiving node as an indicator of the distance between a pair of transmitting and receiving nodes. By using $RxPr$, the relative mobility between a pair of nodes $X$ and $Y$, $M^{\text{rel}}(X)$, is then calculated at the receiving node, $Y$, as follows:

$$M^{\text{rel}}(X) = 10 \log_{10} \frac{RxPr^{\text{raw}}_{X \rightarrow Y}}{RxPr^{\text{raw}}_{X \rightarrow Y}} \quad (1)$$

$RxPr^{\text{raw}}_{X \rightarrow Y}$ is the power level detected at the receiving node $Y$ for the first successive packet transmission from node $X$ while $RxPr^{\text{raw}}_{Y \rightarrow X}$ is the power level detected at the receiving node $Y$ for the second successive packet transmission from node $X$. If $RxPr^{\text{raw}}_{X \rightarrow Y} > RxPr^{\text{raw}}_{Y \rightarrow X}$, then $M^{\text{rel}}(X) > 0$. On the other hand, if $RxPr^{\text{raw}}_{X \rightarrow Y} < RxPr^{\text{raw}}_{Y \rightarrow X}$, then $M^{\text{rel}}(X) < 0$. A positive value of $M^{\text{rel}}(X)$ indicates that the distance between the two nodes is decreasing, meaning the nodes are moving closer to each other while a negative value of $M^{\text{rel}}(X)$ means that the distance between the nodes are increasing, indicating that the nodes are moving away from each other. A node with $n$ neighbors would have $n$ values of $M^{\text{rel}}$.

In order to adopt the mobility metric in our tag design, we use the relative mobility, $M^{\text{rel}}$ as a node’s or an agent’s tag. Hence, in our approach, each agent has a dynamic tag that changes as it moves. In our view, the relative mobility between agents is suitable for use as tags in mobile environments. The reason is that it has the ability to structure a mobile population into local interaction groups, e.g. nodes moving closer to each other could form a group and vice versa, which satisfies R3. In order to calculate agents’ tags, each agent notifies its neighboring agents two times in a time interval. Based on the received notifications, each agent would measure $RxPr^{\text{raw}}$ and $RxPr^{\text{raw}}$ for each of its neighbors. The exchange of
notifications between two agents is possible only if they are within each other’s transmission range, which satisfies \( R_1 \). When an agent \( X \) receives \( R_{xP}^{\text{new}} \) and \( R_{xP}^{\text{two}} \) of another agent, \( Y \), it calculates agent \( Y \)’s tag using eq. 1. The same process happens for each of \( X \)’s neighbor. Therefore, if \( X \) has five neighbors, then it would have a record of five tags, e.g. \( [+2, +1, -1, +3, -5] \). The first value is the tag of its first neighbor, the second value is for its second neighbor and so forth.

Following the approach proposed by [3], we also define tolerance threshold. In their approach, a tolerance threshold evaluates whether the tags of two agents are similar or not. Based on their tags similarity, it is determined whether they are in the same local interaction group. From this we can infer that the ultimate purpose of tolerance threshold is to determine whether agents are in the same local interaction group or not. If MaTaCo uses the same equation proposed by [3], then MaTaCo would not accurately determine if two agents are in the same local interaction group. This is because the relative mobility between them is used as their tags. For instance, consider a case in which agent \( X \) and agent \( Y \) are neighbors, both’s tags are-1 and the tolerance threshold value is 0. Based on the equation proposed by [3], \( |\tau^X - \tau^Y| \leq T \), where \( \tau^X \) is \( X \)’s tag, \( \tau^Y \) is \( Y \)’s tag and \( T \) is the tolerance threshold, MaTaCo would decide that the two agents are in the same local interaction group. This is inaccurate as the negative tags indicate that the two agents are moving away from each other and there is a possibility that they are moving to outside each other’s transmission range. Therefore it is not suitable for them to be in the same local interaction group. In order to accurately determine if two agents are in the same local interaction group, we use the following equation in which we define the tolerance threshold, \( T = 0 \). It is worth to note that all agents have the same tolerance threshold value. Therefore, in our approach, \( X \) and \( Y \) are considered to be in the same local interaction group only if:

\[
M^{\text{rel}}(X) > T
\]  

(2)

Otherwise, they are considered not to be in the same local interaction group. This means that if \( Y \)’s tag at \( X \) is positive, then \( X \) determines that \( Y \) is in the same local interaction group as itself, otherwise \( X \) considers \( Y \) not to be in the same group. \( X \) also evaluates its other neighbors based on this equation. By incorporating the mobility metric in the design of tag and tolerance threshold, each agent becomes aware of other agents’ mobility. Each agent also becomes responsive to changing mobile environment in the way that it can evaluate whether a neighbor is in the same local interaction group as itself based on their relative mobility. Hence, MaTaCo approach satisfies the mobility-aware and responsive features stated in \( R2a \).

The motivation of using the mobility metric, i.e. eq. 1 and 2, as discussed in [2] are that it does not rely on the availability of location and velocity information (e.g. global positioning system). The mobility metric calculation can be done locally at each agent and the received signal strength can be measured with existing hardware.

**Strategy:**

An agent’s strategy defines the move or action that it will take when it interacts with another agent. In our approach, an agent can choose between two actions i.e. cooperate or defect as its strategy. Furthermore, an agent’s strategy is divided into its strategy with agents that are in the same local interaction group as itself, \( S1 \) and its strategy with agents that are not in the same group, \( S2 \). Therefore, in MaTaCo approach, an agent can cooperate \((C)\) or defect \((D)\) with a neighbor that is in the same local interaction group and cooperate or defect with a neighbor that is in different local interaction group.

\[
S1 = \{C, D\} \quad (3)
\]

\[
S2 = \{C, D\} \quad (4)
\]

This design gives each agent the ability to adapt to changing mobile environment. An agent adapts to changing mobile environment in the way that it can choose to play \( S1 \) or \( S2 \) with a neighbor based on their relative mobility, hence satisfying the adaptive feature stated in \( R2b \). Moreover, it also follows the suggestion by [4] that each agent should possess two traits of strategy i.e., cooperate or defect when interacting with agents that are in the same local interaction group as itself and cooperate or defect when interacting with agents that are not in the same group, in order to avoid the absence of selfish agents in the environment. When each agent possess this traits of strategy, there will be agents that receive cooperation from others of the same tag but always defecting. These agents can be classified as selfish.

**Interaction:**

This section describes the interaction component design which is divided into the designs of scenario, payoff and reproduction of agents.

**Scenario:**

The scenario dictates what kind of interaction that agents play between them. In this thesis, we propose two models to evaluate our approach which are generic and application-specific respectively. In the generic model, agents play a prisoner’s dilemma (PD) game scenario while in the application-specific model, agents play packets forwarding in MANETs.

The motivation for the choice of PD game as the scenario for the generic model is that it represents the scenario of forwarder’s dilemma. Similar to forwarder’s dilemma, in a PD game, agents receive higher scores by defecting than cooperating, independent of their opponent’s move. Therefore defection \((D)\) is the dominant strategy in a PD game; assuming that they always try to maximize their payoffs, they would always choose \( D \). However, the dilemma is that if they cooperate with each other, they would receive better payoffs than if they defect. In our work, we assume repeated interactions between two agents are rare because of the mobility of agents. Moreover, tag-based approaches do not rely on history of interactions. Therefore, we choose one-shot PD game as the generic scenario.

The motivation for choosing packets forwarding in MANETs as the scenario for the application-specific model is that a session of packets forwarding, between a source and a
destination that are far from each other, would involve multi-hop communication. This would serve as a challenge for MaTaCo in enforcing cooperation between nodes in MANETs, especially in the presence of selfish nodes.

**Payoff:**
The payoff function defines the rewards that a pair of agents receive when they play their strategies against each other. The function depends on the scenario that agents are playing.

**Reproduction of agents:**
In a tag-based system, it is assumed that agents always try to maximize their payoffs. The reproduction of agents is based on this assumption. For instance, in the approach proposed by [3], agents with higher payoffs are reproduced more than agents with lower payoffs. Each reproduced agent inherits the tag and tolerance threshold of its parent. In contrast, we adopt the learning interpretation of reproduction where each agent compares its payoff with another agent’s payoff and copies the other’s traits such as tag and tolerance threshold if the other agent has higher payoff than its own [3]. This is similar to Hales and Edmonds’ approach. However, instead of copying the tag and strategy, an agent, in our approach, only copies the strategy of the other agent if the other agent’s payoffs is higher than its own [3]. This is similar to Hales and Edmonds’ approach. However, instead of copying the tag and strategy, an agent, in our approach, only copies the strategy of the other agent if the other agent’s payoffs is higher than its own. We let the tags of agents change according to their movements. The rationale is that if an agent is allowed to copy the tag of a higher scoring agent, then the movements of the agent and its neighborhood need to be controlled so that the agent could have the same RxPr as the higher scoring agent. This is not suitable for mobile environments such as MANETs as each node’s movement follows its own trajectory. Therefore, in our work, we let each agent move according to its own trajectory which satisfies $R2c$, and try to find conditions that promote high cooperation in such a mobile environment.

**Algorithm:**
We propose a distributed algorithm that makes use of the design described in section 3.1. This section describes the algorithm in general. In the next two chapters, the algorithm is adapted according to the agent-based and MANETs models. The algorithm is designed to run locally at each agent, which satisfies $R4$. This is because in self-organized MANETs, nodes are independent of each other and belong to different authorities. Nevertheless, when all nodes in a network run the algorithm, it should lead to global cooperation enforcement in the network. The algorithm is described in the following steps:

1. Send first notification to neighboring agents.
2. Measure the received power level, $RxPr_{one}$, of each first notification received from neighbors.
3. Send second notification to neighboring agents.
4. Measure the received power level, $RxPr_{two}$, of each second notification received from neighbors.
5. If the second notification of a neighbor is not received within a time interval, discard the neighbor from neighbors list.
6. Calculate $M^{rel}$ for each neighbor.
7. Choose $S1$ if playing with a neighbor with $M^{rel} > 0$, otherwise choose $S2$.
8. Compare payoff with a randomly selected neighbor, $j$.
9. Copy $j$’s $S1$ and $S2$ if $j$’s payoff is higher than own’s payoff.
10. Reset payoff.
11. Repeat from step 1 for next generation.

Step 1 to 5 refers to the process of measuring received power levels of neighboring nodes. Step 6 refers to the process of calculating each neighbor’s tag based on the received power levels. Step 7 refers to the process of evaluating whether each neighbor is in the same local interaction group and selecting strategy based on the evaluation. Finally, step 8 to 10 refers to the process of learning interpretation of agents’ reproduction as described in section 3.1.2. Figure 2 shows the flow of the algorithm.

![MaTaCo’s algorithm flow chart. RxP refers to the received power level of the received notification. $M^{rel}$ is the relative mobility between a pair of nodes. A node with $n$ neighbors has $n$ values of $M^{rel}$. $S1$ and $S2$ are the strategies of a node.](image-url)
Design Analysis

In order for a tag-based approach to successfully enforce cooperation between agents in a population, it must be able to divide the population into local interaction groups. This is because only with the existence of local interaction groups in the population, do the agents have the incentives to cooperate in order to maximize their payoffs. Existing tag-based approaches, such as [3], [5] and [6], are successful in enforcing high level of cooperation in populations of stationary agents as they have the ability to divide the populations into local interaction groups. In the approaches, each agent could identify agents that share the same group as itself from the entire population. In MANETs, however, there is a possibility that the existing approaches could not enforce high level of cooperation as MANETs environment is different in the sense that nodes are mobile and have limited transmission range. Their mechanisms are not aware of nodes’ mobility and nodes’ limited transmission range would only allow them to locate group members from their neighborhoods, not the entire network. Therefore, the challenge of a tag-based cooperation enforcement approach, in mobile environment especially MANETs, is to be able to form local interaction groups with the constraints of nodes’ mobility and limited transmission range.

Distinct from existing approaches, MaTaCo is designed to have the ability to divide populations of mobile nodes, especially MANETs, into local interaction groups while simultaneously aware of nodes’ mobility and limited transmission range. By using relative mobility between nodes as tags, nodes that run MaTaCo algorithm should be able to form local interaction groups in a MANET based on their mobility. Moreover, each node only has to identify its group members from its neighborhood instead of the entire network, thus adhering to its limited transmission range. To be more specific, a node would only form a local interaction group with its neighbors that are moving closer to itself. They are identified based on their tags, i.e. positive tags mean that they are approaching while negative tags mean that they are moving away. Based on the principle of tag-based cooperation, a node should be cooperative in its local interaction group in order to maximize its payoff. Thus in this sense, the solution amounts to the enforcement of cooperation between nodes that are approaching each other. This solution is expected to solve the problem of selfishness in MANETs as it adheres to the principle of tag-based cooperation and the constraints of MANETs. In tag-based cooperation, local interaction groups have to be formed in order to ensure nodes prefer to be cooperative rather than selfish while in MANETs, a node can communicate directly only with other nodes that are within its transmission range. Therefore, in MANETs, a local interaction group can only be formed between nodes that are within each other’s transmission range.

With regards to the proposed solution, nodes that are approaching each other, in a MANET, form a local interaction group within their transmission range. If they choose to be cooperative in the group, then they create a cooperative region in the network. Nodes in the cooperative region will gain higher average payoffs compared to a group of nodes that forms a selfish region. Assuming all nodes always try to maximize their own payoffs, the selfish nodes will copy the cooperative nodes’ behavior when they find out that the cooperative nodes are gaining higher payoffs than themselves. Subsequently, majority of nodes in the network will be cooperative. If majority of nodes in the network are cooperative, then any pair of source and destination nodes, which are not within each other’s transmission range, will have a high probability of being able to find a cooperative multi-hop route through the network [6]. This also justifies why the solution targets the enforcement of cooperation with nodes that are approaching rather than those receiving.

Summary

This article presented the MaTaCo approach, a mobility-aware tag-based cooperation enforcement approach in which the enforcement of cooperation takes into account the mobility and transmission range characteristics of wireless agents. Four main requirements for MaTaCo were identified as a consequence to the analysis of existing cooperation enforcement approaches, i.e. aware of nodes’ mobility (R1), aware of nodes’ transmission range (R2), ability to form local interaction groups (R3) and execute algorithm at each node independently (R4). In order to satisfy R1, R2 and R3, MaTaCo incorporates a mobility metric in its mechanism. The mobility metric utilizes relative mobility between nodes as tags which gives MaTaCo the ability to form local interaction groups in mobile environment especially MANETs. With the formation of local interaction groups in MANETs, cooperation between nodes can be enforced based on the principle of tag-based cooperation. R4 is satisfied by ensuring MaTaCo’s algorithm can be run locally at each node without any collaboration. Analysis of MaTaCo’s design was also presented in order to justify why MaTaCo is expected to solve the problem of selfishness in MANETs. The next step is to implement and evaluate MaTaCo in an abstract, mobile environment model and MANET model. Its results in both models will be compared to the performances of existing tag-based models.

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References


