

Sharing Smart Environment Assets in Dynamic Multi-Partner Scenarios

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Abstract—Accurate, reliable and actionable intelligence produced by smart environment assets is essential in order for dynamic operations such as emergency response or humanitarian relief to be effective. Leveraging Future Internet building block technologies, smart environments are ecosystems which seamlessly embed IT assets into physical world's objects that collect, process and disseminate operational data and insights. The management of smart environment assets towards an efficient collaboration in multi-partner, dynamic scenarios where assets are owned and operated by different partners is a non-trivial problem, due to partners' restrictive sharing policies. In this work we compare two asset sharing approaches; the first is based on a traditional asset ownership model, while the second novel one, is based on an *edge* team-based model where users are grouped into cross-partner teams and as team members they have access to assets belonging to all the partners participating in team. We further experiment with the second, unexplored team-based sharing model by testing its behavior under different user mobility patterns and extreme asset ownership models investigating its impact on MSTA-P, a policy-regulated version of an existing asset-task assignment protocol. For the protocol's evaluation we implement a multi-partner operation scenario using an open source, agent-based and discrete time simulation environment.

I. INTRODUCTION

The successful outcome of unexpected and highly dynamic operations such as emergency response and humanitarian relief, vastly relies on processing and dissemination of actionable information and valuable intelligence about operational state and changes. Exploiting recent advances in information technology including the Internet, smart sensors, communication protocols and cheaper computing power this intelligence is nowadays increasingly produced by “smart environments”. Smart environments are ecosystems composed of infrastructures that blend physical and IT assets, wherein sensors, network connectivity and data storage are embedded seamlessly in physical world's objects that collect, process and disseminate operational data and insights [1].

Recent examples of natural disaster situations, such as those that unfolded in during the Haiti earthquake¹, the damaged utility facilities in the BP oil spill case², and the Fukushima

Daiichi nuclear disaster³, demonstrated the need for emergency responders such as first aiders, rescuers and engineers, affiliated with different national and organizational groups to form cross-organizational teams and share assets in an ad-hoc manner, in order to provide humanitarian assistance. These assets are shared across organizations to enable quick decision making. Typically, collaborating partners have their own inherent restrictions, which are stated as a set of policies (including security and privacy policies) on how to share their infrastructures with other organizations.

Sharing smart environment assets to support multiple concurrent and multi-organization missions is a non-trivial problem. Collaborating organizations have different backgrounds (e.g. area of expertise, cultural background) which reduce shared awareness and understanding of the mission, leading to different decisions about what assets can be shared, with whom, and when [2]. Moreover asset sharing is an agile and time critical process given the highly dynamic scenarios that we cope with (unexplored and volatile environment, short-lived and mutable collaborations etc). In [3], we formalize, evaluate and compare two asset sharing policies; the *asset-centric* sharing model, which is based on the traditional asset ownership paradigm according to which assets belonging to a collaborating partner may or may not be shared with other partners based on pre-defined policies [4] and the novel, dynamic *team-centric* sharing model, which is inspired from military operations and is based on the *edge* scheme [5], which allows for more dynamic formation of teams and assets sharing patterns to emerge.

The team-centric sharing model is applicable to real world scenarios thanks to Future Internet building block technologies [6] such as, ad-hoc network connectivity [7] and distributed middleware infrastructure [8], which allow for direct communication and management of assets and services that belong to disparate administrative domains. In current work, we (1) briefly demonstrate the results in [3] and we further experiment with the novel, unexplored edge team-centric sharing model by (2) testing its behavior under different user mobility patterns and (3) extreme assets ownership models. While there is large literature about policy-based networking environments management, the majority of these investigate

¹Haiti Earthquake Response: Context Analysis - <http://tinyurl.com/k8cfff7>

²Deepwater Horizon oil spill - <http://tinyurl.com/ke27b6c>

³Fukushima Daiichi nuclear disaster - <http://tinyurl.com/mp97hqv>

the problem at the systems level. The team-centric approach introduces a method, which includes the organizational and system/network administrator (human) levels in the policy-management process of a multi-domain network, recognizing that sharing and allocation of resources to teams is the first step for enabling policy-based management in dynamic networked systems, formed in an ad-hoc manner. Thus, we want to further investigate the dynamic and event-driven, team-centric model, which we believe has been partially overlooked by previous work. As a metric for team-centric sharing model evaluation we investigate its impact on the policy regulated Multi-Sensor Task Allocation (MSTA-P) protocol [3], which addresses the problem of allocating heterogeneous bundles of smart environment assets to a variety of different responders tasks, with the goal of maximizing the usefulness of assets and satisfying the most critical task requests.

For the evaluation of team-centric sharing approach, we use a discrete-time, multi-agent, simulation environment. We find that (1) the protocol behaves better when the nomadic community inspired mobility model is applied, and (2) the team-centric sharing model behaves efficiently in response to extreme ownership proportion for teams' heterogeneity greater than 75%.

In Section II we discuss previous asset sharing policy approaches applied in multi-partner operations and analyze emerging issues in such environments. In Section III we briefly describe the aforementioned sharing policies, we present the policy-regulated MSTA-P protocol and define the variables we consider for its performance evaluation. Section IV describes the experiments through which we evaluate MSTA-P's performance and presents the simulation's results. In Section V we present future work.

II. BACKGROUND & RELATED WORK

Organizations in dynamic coalition operations commonly work in peer-to-peer formations acting as servers and/or clients providing and/or dynamically consuming information resources provided by others. In order for a multi-partner coalition to operate effectively, it is necessary for information to move across the organizations' boundaries efficiently and secured [9]. Thus, amongst others coalition partners need a number of constraints, which regulate access control on their resources in order to establish smooth collaboration. The sharing restrictions are usually expressed through policies, which are commonly defined via condition-action pairs, where specified actions are executed if conditions evaluate to true.

Well known asset sharing approaches in multi-organizational environments are represented by [10]–[13]. In particular, [10] proposes a model where new collaborating members can only have access to a specific resource if they are first invited by authorized partners and [11] proposes a role-based framework that combines users' characteristics with parameters such as time and user IP address, allowing or denying access to resources accordingly. [12] introduces a concept-level semantic model granting access to resources considering semantic relationships supported by the ontology,

while [13], is based on an automated trust negotiation approach focusing on a type of "contract" in which collaborating partners agree to share their resources over a given time period.

Although all the above models cope with resource sharing in a secure and confidential manner, they are likely to fail or encounter difficulties in being applied to highly dynamic environments. In order for all of them to comply with situational changes, an extra overhead is needed due to the spatial or chain of command distance between the decision making center, and therefore the policy making centre, from where the changes take place. Differently, the edge, team-based sharing model presents much lower overhead regardless the situational changes frequency. The teams at the network edge – being event-driven entities – are formed, reformed or disassembled as a response to environmental changes therefore, sharing policies based on this model are always up-to-date to unfolding operations.

When policies are applied, policy conflicts, i.e. policies whose actions contradict with each other is an issue that needs to be addressed. The work reported in [14] and [15] proposes a policy precedence relationship to decide which one of the conflicting policies should first apply. We assume that there are no conflicts either in asset-centric or team-centric sharing models. This is justified considering the one dimensional nature of our policies, i.e. each of the resources is never owned by more than one partner and each user either belongs or not to a single team.

Finally, in scenarios where mobile users are involved the modality with which they may move on the operational field needs to be investigated. Several mobility models have been proposed and some of the most broadly used are presented in [16]. In our experiments we test team-centric sharing model under two mobility models. In the first one, the mobile user nodes are free to move with no constraints, independently of other nodes using a *random waypoint mobility model* and we refer to this as *Moving User Model*. In the second model we apply a more realistic mobility approach inspired by the *nomadic community model* [17], where teams' users follow their teams' leaders. Therefore, in this model there is a spatial dependency among node's movement and we refer to this as *Moving Team Model*.

III. ASSET SHARING POLICY MODELS AND MSTA-P PROTOCOL DEMONSTRATION

The asset sharing models that we propose and experiment with are binary; that is they either give or not access to assets' services. We acknowledge the existence of finer-grained asset sharing models, which using techniques such as obfuscation [18], can grant access to subsets of services' capabilities. The investigation of finer-grained sharing approaches are outside the scope of this work. However, we assume that ours and fine-grained models complement each other and that one can provide multi-level asset sharing management by combining the two. Consider for example the case where there are three sharing grades of a service (e.g. gold, silver, bronze). Using the

sharing grade parameter as input in our models we can support multi-level sharing patterns (i.e. $\text{canAccess}(U, A, \text{silver})$ see Algorithm 1).

The first sharing model is based on the traditional ownership approach. It considers a mechanism making resources either available for any partners to use or alternatively reserving them for the exclusive use of the owning partner. We experiment with different sharing levels by allowing collaborating organizations to share different proportions of the assets they own. We refer to this policy model as *asset-centric sharing*.

In typical multi-partner operations usually there is a number of smaller, more focused formations, which are dynamically created in response to an on the field event and execute missions for only a short time [19]. In the second sharing model, we abandon the asset-centric sharing model, assuming collaborating partners share none of their owning resources “by default”. Instead, following the *edge* model we introduce a mechanism of cross-partner formations (small, focused formations), which we call *teams* and allow users participating in the same team to share assets freely [20]; therefore team members have access to all assets owned by any organization represented in the team. We call this *team-centric sharing* model and we experiment with a variety of sharing levels by applying different degrees of homogeneous (comprise members from a single partner) & heterogeneous (comprise members from two or more partners) teams.

The initial MSTA distributed protocol (the reader is referred to [21] for more in depth description of protocol’s algorithms) runs on two main entities, (1) the user devices (e.g. smart phone or tablet) and (2) the smart environment assets and it consists of two main stages:

- *The initial negotiation stage*: the user devices respond to user generated tasks requests, compute the best set of assets which may satisfy the request, and distribute the generated bids to this optimal set of assets.
- *The bundle formation stage*: the assets decide upon which bundle to join in order to serve a particular task, giving priority to the most important tasks to which they can provide the highest average utility

Each task in the protocol amongst other features (task priority, utility demand and area of interest) is characterized by an expiration time (i.e. a deadline within which the task must be supported by an assets bundle or alternatively must be dropped) and a duration time (i.e. time during which the task remains active on the field). Provided that available resources are scarce, we assume that a subset of created tasks will not be supported, which implies the need for dropped tasks. A task is considered dropped (i.e. unsupported by the smart environment network), if there are no available resources to satisfy the task utility demand in the initial negotiation stage, or if no resource can provide support to the task on time during the bundle formation stage. We refer to the set of these tasks as *dropped tasks*.

Algorithm 1 performs the MSTA-P *initial negotiation stage* steps. The policies evaluation is the first process which is executed in the protocol after the creation of a task. When

Algorithm 1 MSTA-P

```

for all  $A$  within  $SR$  do
  if  $\text{canAccess}(U, A)$  then
     $\text{addCandidateAsset}(A)$ 
  end if
end for
for all  $\text{candidateAsset}[A]$  do
  if  $\text{canServe}(A, T)$  then
     $\text{addBundle}(B_{AT})$ 
     $\text{calculateUtility}(B_{AT})$ 
  end if
end for
 $\text{distributeBundle}(B_{AT})$ 

```

the users create a new task, their devices query the assets within a sensing range SR of the area of interest in order to create assets bundle able to serve the task. The sharing policies are considered at this step taking into account if the tasks’ creators can access a specific asset based on the sharing policies set by coalition partners (i.e. if $\text{canAccess}(U, A) == \text{true}$). As a result of the policies’ evaluation is the creation of a list of assets that could be accessed by the task’s creator. We call this set of assets *candidate assets per task*. Therefore, the sharing policies affect the assets bundles creation by limiting the number of assets a user can access based on the applied sharing policies. In next section we use these two variables, the *candidate assets per task* and the *dropped tasks %* as indicators of the protocols performance for sharing models’ evaluation.

Algorithm 2 Bundle Formation

```

for all  $A$  of bundle  $B$  do
  if  $\text{isFree}(A)$  then
     $\text{accept}(L[B_1])$ 
  else
    if  $\text{calculateUtility}(B_1) \gg \text{calculateUtility}(B_{\text{current}})$ 
    then
       $\text{accept}(L[B_1])$ 
    else
      return busy
    end if
  end if
end for

```

Algorithm 2 performs the steps of the second, *bundle formation stage* of the protocol. At this stage each asset node keeps a list $L[n]$ of bids in which it is involved. The list is sorted by decreasing average contribution (i.e. bundle utility divided by number of assets composing the bundle). If an asset is currently not serving any task (i.e. is free) then it accepts to serve the first bid of the list. Otherwise if it is currently allocated to a task it will only be preempted from the current and accept serving the new one if the contribution to the new task is strictly greater than the current one (i.e. $\text{utility}_{\text{new}} \gg \text{utility}_{\text{current}}$). If any one of the assets in the bundle does

not accept to serve the task then a new bid (i.e new pair of assets bundle, joint utility) is created and distributed by the initial negotiation stage Algorithm 1.

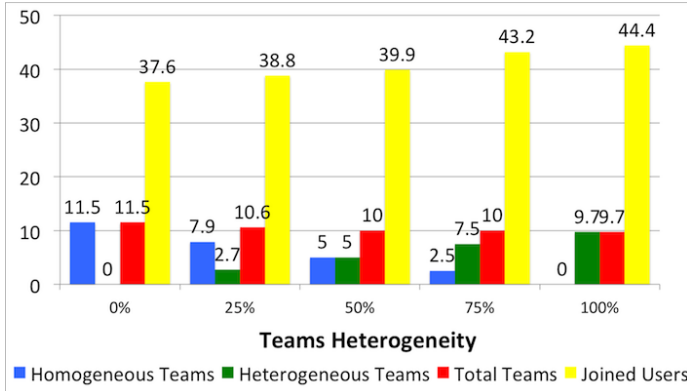


Fig. 1. Teams statistics: Number of Homogeneous/Heterogeneous teams & teams' Joined Users

IV. SIMULATION RESULTS

For the implementation and evaluation of MSTA-P protocol we use REPAST Symphony⁴, an open source agent-based, discrete time simulation environment. Using the platform we simulate a smart environment network, composed of heterogeneous static “smart” infrastructures and mobile users. In our experiments we use the most effective (in terms of highest overall profit achieved and low network traffic overhead) version of the MSTA-P which we call *Cost-driven Preemption* (the reader is referred to [21] for more in depth analysis of the protocol). The task creation (i.e. users demand for asset services) rate is stable at arrival rate equal to 1 task per timestep and we repeat each simulation 10 times for 10000 timesteps averaging the measurements.

Implementing a multi-partner operation scenario we assume 2 partners (partner A and partner B), 250 static assets and 50 mobile user nodes, which are randomly deployed on a 2D grid of 500m x 500m. The users are equally distributed to each partner (partner A = 25 users, partner B = 25 users). In the experiments, teams of users are formed at the first timestep and they do not change until the end. Each team consists of minimum two members while there is no upper bound on team's members. All the users are identical in terms of capabilities and responsibilities, apart from one user for each team who is the team creator and leader. At simulation's first timestep, 25 out of 50 users are randomly selected (using java.util.Random, 48-bit seed) as candidate team leaders. Each one of them consecutively queries the nearby users within a radius of 100m in order to create a team. We call this radius *Team Range = 100m* (TR). If the queried users are free (i.e. do not belong to any team), the team leader adds them to their team. Each user belongs to maximum 1 team at a time, while there are users who do not belong to any team.

⁴repast.sourceforge.net - last checked December 9th, 2013

A. Teams Statistics

Figure 1 demonstrates the teams statistics. We present the teams' statistics here because the performance of the team-centric sharing model is fully associated with the number of users involved in teams. We note that as the degree of teams heterogeneity increases, the total number of users involved in teams increases as well. This is due to the restrictive “users from the same partner” condition that applies in the homogeneous teams' formation. Thus, there are ~38 joined users for 0% and ~44 for 100% teams heterogeneity while the overall average proportion of users joined to teams is near 80% of the total users. Additionally, the average number of users per team (i.e. $\frac{JoinedUsers}{TotalTeams}$) increases while the degree of teams heterogeneity increases as well, while the overall number of teams slightly drops.

B. Sharing Models Evaluation

In order to have a complete picture in evaluating and comparing the two asset sharing models, we experiment in asset-centric model by linearly increasing its sharing level starting from minimum 0% sharing ratio (none of the assets are shared with non-owning partners) and increasing it by 25% for each experiment until maximum 100% sharing ratio (all of the assets are shared with non-owning partners) is reached. In team-centric model we start with the minimum sharing level 0% heterogeneous teams (all the teams in the field are homogeneous) and we increase it linearly by 25% for each experiment until reaching the maximum sharing level 100% heterogeneous teams (all the teams in the field are homogeneous). In essence, by increasing the degree of teams heterogeneity, indirectly we increase the overall shared assets but unlike the first sharing model we do so through user teams.

Figure 2 compares the two sharing models in terms of their effects on MSTA-P performance, when the 250 asset nodes are equally distributed to the collaborating partners (partner A = 125 assets, partner B = 125 assets) and user nodes move under Moving User Model. In both models the starting point is the same because we start from minimum sharing levels (0% asset sharing ratio & 0% teams heterogeneity).

In asset-centric model when the sharing ratio is at its maximum (i.e. 100%) the number of candidate assets per task is twice as much as when the sharing ratio is at its minimum level (i.e. 0%). The difference in dropped tasks proportion is even larger. The total dropped tasks when the sharing ratio is at its maximum are almost 8 times smaller compared to when the sharing ratio is at its minimum. We also notice that by increasing linearly the sharing ratio, the number of candidate assets has quasi-logarithmic increase, while symmetrically the number of dropped tasks decreases quasi-logarithmically. Moreover, we observe that the difference of candidate assets per task and dropped task proportion moving from 75% to 100% assets sharing ratios is significant smaller compared to when we move to higher sharing ratios at lower sharing levels (e.g. from 0% to 25%). The margin between 75% and 100% is 2 assets per task and 3% units in dropped tasks, while the margin moving from 0% to 25% sharing ratios is

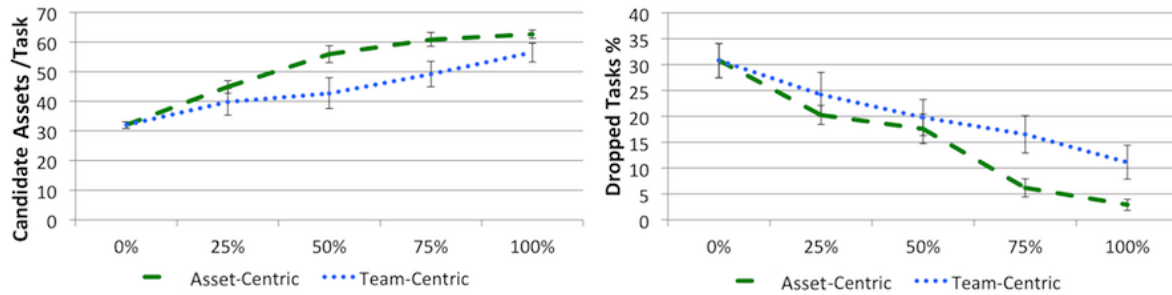


Fig. 2. Asset-centric vs. team-centric sharing models: effect on candidate assets per task and dropped tasks %.

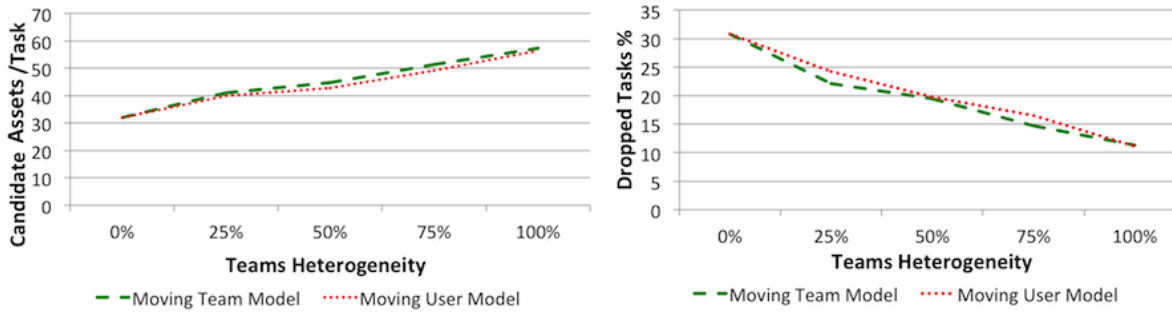


Fig. 3. Team-centric sharing model: effects of different Mobility models.

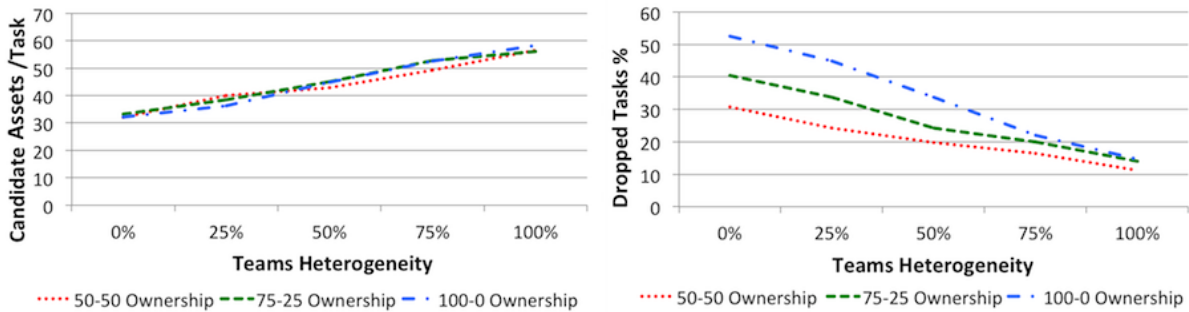


Fig. 4. Team-centric sharing model: effects of different Ownership proportions.

11 assets per task and 10% units in dropped tasks. Therefore, the protocol seems to perform efficiently with short variation in asset-centric approach for sharing ratios larger than 75%.

As for the team-centric model, in 100% teams heterogeneity case, the number of candidate assets per task almost doubles and the dropped tasks is three times smaller in comparison to when the degree of teams' heterogeneity is 0%. Moreover, in the team-centric sharing model we observe that by increasing linearly the team's heterogeneity ratio we obtain a quasi-linear increase in the number of candidate assets per tasks and symmetrically a quasi-linear decrease in the number of dropped tasks. Overall, asset-centric seems to be more effective than team-centric model, especially in terms of dropped task %. In fact the proportion of the dropped tasks, when the level of both sharing policies reaches its maximum, is less than 5% in the asset-centric approach and more than 10% in the team-

centric approach. This is due to the fact that only an average of 80% of the users belong to teams due to the team formation mechanism we adopt. This means that even in the case of 100% heterogeneity almost 20% of the users do not benefit from the team sharing mechanism.

C. Mobility and Ownership model Evaluation

In Figure 3 we compare the MSTA-P protocol behavior under two different mobility models (Moving User Model & Moving Team Model)⁵. In the second model the mobile user nodes, members of a team are restricted to move within a radius of TR (100m) from their mobile team leader. The results indicate that the protocol behaves slightly better when the Moving Team Model is applied, displaying for each of the

⁵No ErrorBars in Fig. 3 and Fig. 4 due to marginal results

different team heterogeneity degrees an average of 1 additional available candidate asset per task and 2% less dropped tasks, compared to the unconstrained mobility model.

In the fourth set of experiments, represented by Figure 4, we make three different assumptions in terms of asset ownership proportion. In the first case the resources are equally owned by the partners 50% - 50% (as in previous experiments), in the second case the asset distribution is 25% - 75% and in the third and most extreme case, the distribution is 0% - 100% (only one of the partners owns all the available resources). We do so in order to measure the team-centric policy behavior in extreme ownership-proportion conditions, which are common in dynamic scenarios like the ones we investigate. User nodes again move under Moving User Model. In each of the three ownership cases the proportion of the assets that can be accessed by users of each partner is stable at 50% of the total regardless the ownership model. For this reason by linearly increasing the degree of teams heterogeneity the candidate assets per task variable is almost equal for each ownership case following a quasi-linear increase pattern. As for the dropped tasks % variable, when the degree of teams' heterogeneity is at its minimum (i.e. 0%), the margin of dropped tasks among different asset ownership proportions is very large (~10). By increasing the team heterogeneity, the dropped task % in all ownership cases tend to the same point (~13%). Finally, the protocol seems to be less affected by the resource ownership inequalities when the degree of team heterogeneity is higher than 75%. The margin between 25%-75% and 0%-100% ownership cases is less than 1% while between these two and 50%-50% case is ~2% dropped tasks %.

Summarizing the results, we conclude that asset-centric model performs better than team-centric but not with a large margin. We identify a cut-off threshold at 75% of assets sharing ratio, above which MSTA-P protocol seems to perform without significant changes in asset-centric model. Finally, we observe that the protocol behaves better when the Moving Team Model is applied compared to the Moving User Model, and that team-centric sharing model behaves efficiently in response to extreme ownership models for team's heterogeneity greater than 75%.

V. FUTURE WORK

We are currently working on the development of more transparent policy-based management systems (PBMS) leveraging controlled natural language technologies. In particular we use Controlled English (CE) [22] as a means to define both, policy rules and components of the managed system. We develop a framework that is able to execute policy analysis (i.e conflict analysis and policy refinement) leveraging CE's reasoner and rich semantics provided by its ontologies. Using a human-friendly and machine processable representation, the proposed framework allows non-technical users at the edge of the network to form, reform and negotiate quickly policies for managing assets in dynamic environments.

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