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Layered Architecture Consistency for MANETs: Introducing New Team Members

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Abstract: In this paper we extend our results (as given in [PHE+07]) concerning the layered architecture for modeling workflows in **M**obile **A**d-Hoc **NET**works (MANETs) using algebraic higher order nets. MANETs are networks of mobile devices that communicate with each other via wireless links without relying on an underlying infrastructure. Workflows in MANETs can be adequately modeled using a layered architecture, where the overall workflow, the team members' activities and the mobility issues are separated into three different layers, namely the workflow layer, the mobility layer and the team layer. In [PHE+07] a formal notion of layer consistency was suggested. Here we extend that approach to allow changes of the interfaces of the gluing of the workflow and the mobility layer.

Keywords: MANET, Architecture, Workflow, Formal modeling

1 Introduction

Mobile Ad-Hoc Networks (MANETs) can be considered as a kind of wireless, self-configuring networks consisting of mobile nodes, that communicate independently of a stable infrastructure and organize themselves arbitrarily. So the network's topology changes continuously and unpredictably depending on the actual position and availability of the nodes. A typical example is a team of team members communicating using hand-held devices and laptops as e.g. in the disaster recovery scenario in Section 4.

In [BDHM06] modeling of workflows in MANETs using algebraic higher order nets (AHO nets) has been introduced. AHO nets are Petri nets with complex tokens, namely reconfigurable place/transition (PT) nets [EHP+07] consisting of PT nets as well as rules and net transformations for changing these nets. To give an intuition of that approach we illustrate the execution and the adaption of a token net in the subsequent figures. In Section 4 this example is presented elaborately. The firing of transition **Workflow Execution** yields the firing of the token net **PN1** and the firing of transition **Workflow Adaption** yields the transformation of the net via the rule **rule_q**.

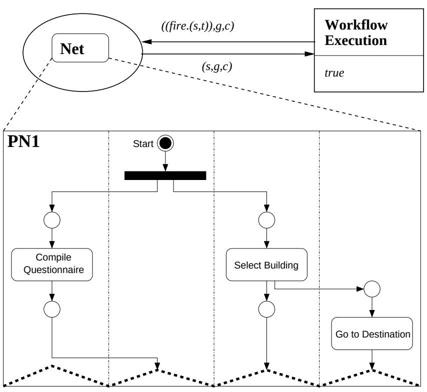

Fig. 1. Execution of token nets

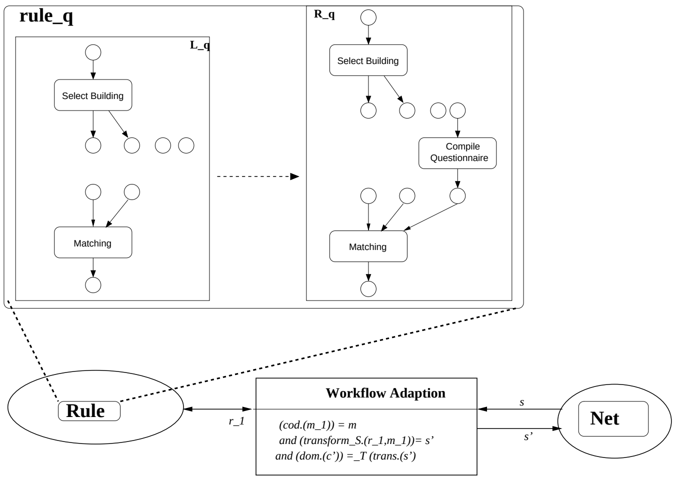

Fig. 2. Adaption of token nets

In [PHE+07] we have developed a layered architecture of the model that allows the separation of support activities concerning the network from activities concerning the intended workflow. This yields better and conciser models, since supporting the network connectivity has a much finer granularity than the more or less fixed workflow execution. There the layered architecture of AHO net models of workflows in MANETs distinguishes three layers, the workflow layer, the mobility layer and the team layer. The workflow layer describes the overall workflow that is to be achieved by the whole team. The mobility layer describes the workflows in order to maintain the MANETs connectivity. The team layer describes the individual activities of the team members. Moreover, we provide a set of rules in each layer for the transformation of corresponding PT nets expressing different system states. Layer consistency means that these layers together form a valid AHO net model of workflows in MANETs.

Related work on distribution of workflows in a possibly mobile setting can be found e.g. in [vdAW01, KMR03, BMM04, MM05] where a unique workflow is divided on the one hand in different autonomous workflows and on the other hand the resulting workflows are adapted by using inheritance resp. graph rules. In contrast we present a layered architecture, where a global workflow and its transformation are separated into three different parts, each of them relevant for a specific aspect of workflows in MANETs. The work presented here as well as in [PHE+07, BMH06] is developed together with research projects[1] where an adaptive workflow management system for MANETs specifically targeted to emergency scenarios, is going to be implemented.

2 Review of Layered Architectures for Mobile Ad-hoc Networks

In [BDHM06] a model for MANETs is described by a global workflow and its transformation by a global set of rules. Following the observation that a workflow in MANETs

[1] MOBIDIS - http://www.dis.uniroma1.it/pub/mecella/projects/MobiDIS, MAIS - http://www.mais-project.it, IST FP6 WORKPAD - http://www.workpad-project.eu/

consists of different aspects we provide a layered architecture as depicted in Fig. 3 to obtain a more adequate model. We separate movement activities from general activities and allow a local view of team members that is most important in such an unstable environment. From a practical point of view the MANET topology often has to be restructured to maintain the network connectivity resulting in a change of movement activities while general activities are more or less fixed during the workflow execution. Thus, the global workflow, based on a predictive layer, is separated into three different layers. Each of these layers is equipped with its own PT nets and transformation rules. The advantage is that we exploit some form of control on rule application by assigning a set of rules to a specific layer. Under these restrictions transformations can be realized in a specific layer of our model.

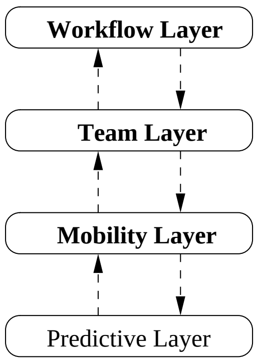

Fig. 3. MANET architecture

The predictive layer signals probable disconnections to the upper mobility layer. The predictive layer implements a probabilistic technique [DRMM05] that is able to predict whether in the next instant all devices will still be connected. The the workflow layer is represented in terms of a PT net[2]. and similarly, the mobility layer summarizes movement activities of the involved team members and is in charge of managing those situations when a peer is going to disconnect. The team layer realizes the local view of team members onto the workflow and the mobility net. Here, a PT net describes those activities being relevant for one team member.

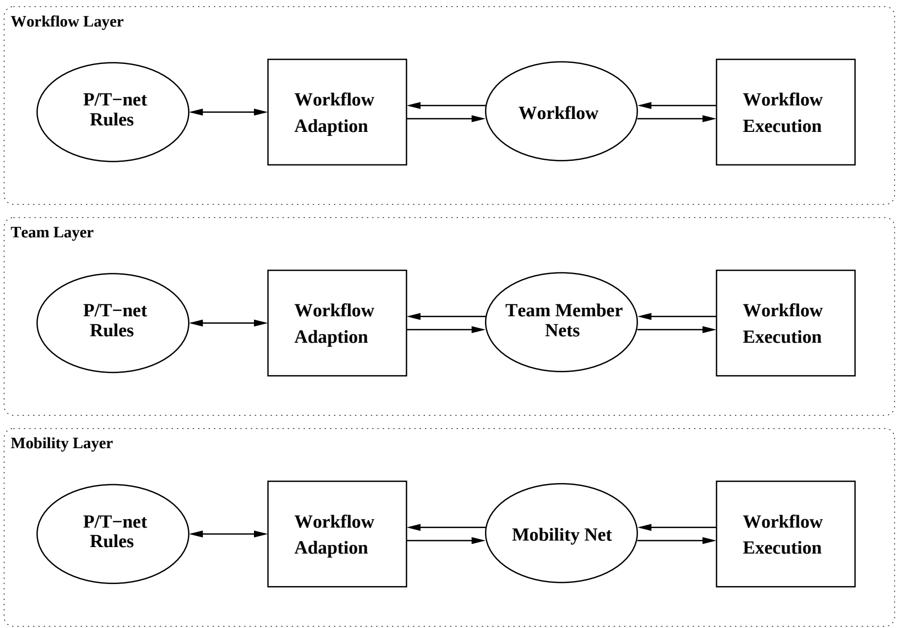

Fig. 4. Layered architecture for supporting cooperative work on MANET

[2] Note that we have a PT net that describes the workflow, but this needs not be a workflow net in the sense of [vdAH04].

The layered architecture is formalized by a layered AHO net (see Fig. 4 for a schematic view), so that rules in a certain layer are provided for transformations of corresponding PT nets, e.g. to react to some incoming events. At this level of abstraction the *nets in nets*-paradigm is reflected in each layer.

AHO nets [HME05] combine an algebraic data type part and Petri nets by the inscription of net elements with terms over the given data structure. Technically, the data type part of the AHO net in Fig. 4 consists of reconfigurable PT nets (see [HME05, EHP+07]), comprising the well-known token game as well as rules and rule-based transformations in the sense of the double pushout (DPO) approach [EP04]. The data type part specifies all by appropriate sorts and operations. In this way reconfigurable PT nets are tokens in our model and the token game as well as the rule-based transformations can be used for the net inscriptions. Moreover, places in the layered AHO net are either system or rule places, i.e. the state of our model is given by an appropriate marking consisting of token nets and token rules. Token rules are static, i.e. rules represented as tokens do not move and remain unchanged on the corresponding rule places (indicated by the double arrow). In short, firing a transition **Adaption** changes the structure of a corresponding token net according to an appropriate token rule (for details we refer to [HME05]). Specifically, the mobility layer is in charge of catching disconnection events incoming from the predictive layer and modifying the mobility net (e.g. adding a “Follow Member X” activity) by applying transformation rules.

The PT nets presented in Section 4 are possible markings of our AHO net model in Fig. 4. Fig. 8 depicts the token net W_0 for the workflow layer, i.e. it represents the current marking of the place **Workflow** in Fig. 4. For the mobility layer in Fig. 10 the token net M_0 is depicted (token net on the place **Mobility Net** in Fig. 4). Finally, the team member nets in Fig. 11 and Fig. 12 are tokens on the place **Team Member Nets** in our model. Note that in general we consider the initial marking of the token nets. This requires changing from PT nets to PT systems so that firing a transition **Workflow Execution** in our model (see Fig. 4) computes the successor marking of a token net. In [PHE+07, BMH06] and in this paper we prefer the notion of PT nets since the structure of token nets is the main focus.

3 Concepts and Results for Layer Consistency

In this section we discuss the basic concepts for maintaining consistency in our approach. Consistency is defined for the layered architecture of workflows in MANETS that is the *workflow layer*, the *mobility layer* and the *team layer*. We present a notion of consistency, that relates the layers to the team members' activities. Moreover, we have rules and transformations for changes at the level of the interface, the workflow layer, of the mobility layer and for changing the individual activities of the team members. These rules and transformations allow the refinement of the workflow according to the imperatives of the network maintenance. Especially as an extension of [PHE+07] we allow the introduction of new team members by transforming the interface.

3.1 Review of Consistent Layer Environment

Based on [PHE+07] the layered architecture for MANETs comprises the *workflow layer* – a PT net W, the *mobility layer* – a PT net M, and the *team work layer*– for each team member a PT net $\mathbf{t^m}$. For each team member $m = 1,...,n$ we provide a net $\mathbf{t^m}$ representing their individual activities as well as the relation to the activities of the whole team and rules changing these activities.

Definition 1 A *consistent layer environment* according to the layers in Fig. 4 is given for the team members' nets $\mathbf{t^1},...,\mathbf{t^n}$, the workflow W and the mobility net M if the following conditions are satisfied:

1. In order to have refinement of places in W with subnets of M we allow replacing W by $\underline{W} \stackrel{pg}{\to} W$, where pg is a place gluing morphism (bijective on transitions and surjective on places).

2. There is the interface net I included in M and W, so that a teamwork net T is obtained by the gluing of M and W along I, written $T = M +_I W$.

3. There are activity arrows for each team member $\mathbf{t^1} \stackrel{\alpha^1}{\to} T,...,\mathbf{t^n} \stackrel{\alpha^n}{\to} T$ that are injective net morphism relating a team member's activities – given by the net $\mathbf{t^m}$ – to the teamwork net T.

The morphism $\underline{W} \stackrel{pg}{\to} W$ is an place-gluing morphism (bijective on transitions and surjective on places) that allows place refinement $W \stackrel{pg}{\leftarrow} \underline{W} \to T$, where the places $pg^{-1}(p)$ are replaced by the corresponding subnet in T. Connecting the mobility layer with the workflow layer is achieved by gluing the mobility net M to the workflow net $\underline{W}$ via some fixed interface net I. The results of this gluing yields the teamwork net T, formally constructed as the pushout **(PO)** in Fig. 5 and denoted by $T = M +_I \underline{W}$. For each team member there is a net morphism that relates the team member's activities, given by the net $\mathbf{t^m}$, to the teamwork net T. This net morphism is called the activity arrow α^m and relates the team member's activities – given by the net $\mathbf{t^m}$– to the teamwork net T.

$$\begin{tikzcd} & I \arrow[dl] \arrow[dr] & & \\ M \arrow[dr] & \textbf{(PO)} & \underline{W} \arrow[dl] \arrow[r, "pg"] & W \\ \mathbf{t^m} \arrow[r, "\alpha^m"] & T & & \end{tikzcd}$$

Fig. 5. Consistent layer environment

The activities of the team members consist of parts concerning their workflow as well as parts concerning their mobility. Team members can change their team member nets according to specific rules. The main goal of our approach is modeling the changes that occur for reasons of the tasks to be achieved as well as the changes that are required because of the mobility issues. In [PHE+07] we already supply the workflow W and rules r^W for transforming W, the mobility net M and rules r^M for transforming M as well as each team member's net $\mathbf{t^m}$ and rules $\mathbf{r^m}$ to transform these. These rules are given as net rules and transformations in the DPO approach (see for example [EP04]). The nets W, M, and $\mathbf{t^m}$, as well as the rules r^W, r^M and $\mathbf{r^m}$ are the tokens in AHO net depicted in Fig. 4. Firing in this AHO net causes the transformation of nets in all three layers at the level of the tokens, i.e. the layer nets and their rules. Consistency of such a layered AHO net means in a broad sense that the workflow W, the mobility net M and the individual team member net $\mathbf{t^m}$ of each team member have to be related as depicted in Fig. 5. In [PHE+07] the interface net remains fixed. In this paper we allow the transformation of the interface and so provide the possibility to introduce new team members.

3.2 Transformations of the Interface

We model changes using rules and transformations at the different layers. The transformation of the interface I, the mobility net M, the workflow W and the team members' activities $\mathbf{t^m}$ is achieved using net transformations as introduced in [PHE+07]. There the interface remains fixed leading to the disadvantage that both the mobility net and the workflow net might contain a number of separated places from the beginning. This means especially that the number of team members is fixed, since the interface glues the workflow and the mobility parts of the team members. Here, we additionally take into account the transformations of the interface I, i.e. given a transformation $I \overset{r}{\Longrightarrow} J$ and corresponding transformations of the mobility and workflow nets we obtain a next consistent layer environment provided specific conditions hold. For that purpose we need the notion of specialization $spec(r)$ for the given transformation. A specialization of a transformation can be considered as a new rule that again can be applied to another net (see Theorem 1). Based on this specialization we have the new *Union Theorem for Interfaces* (see Theorem 2) that characterizes the way an interface of a union can be changed. The details can be found in [BMH06].

Let there be the transformations $W_0 \overset{spec(r)}{\Longrightarrow} W_1$ and $M_0 \overset{spec(r)}{\Longrightarrow} M_1$. We first need to ensure *compatibility with place refinement* (see Def. 2 in [BMH06]) This means that the rule $spec(r)$ is also applicable to $\underline{W}_0$ and there exists a place-gluing morphism $pg_1 : \underline{W}_1 \to W_1$, such that the diagram **(1)** in Fig. 6 commutes. Moreover, there have to be suitable activity rules, so that for each m there are activity rules $\mathbf{r^m}$ over r and we have conformance of activity rules and team member nets (see Def. 3 and Def. 4 in [BMH06]).

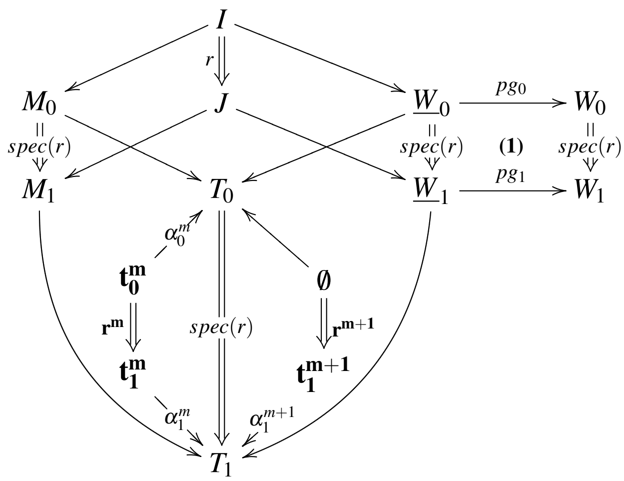

Fig. 6. Introducing a new team member

Example 1 *Starting at a consistent layer environment we may have the situation depicted in Fig. 6: There is the rule r changing the interface, that is extended to the specialization $spec(r)$ in the mobility layer and in the workflow layer. In the team layer rules r^m are applied for each team member m yielding the following transformations $M_0 \overset{spec(r)}{\Longrightarrow} M_1$, $W_0 \overset{spec(r)}{\Longrightarrow} W_1$ as well as transformations $\mathbf{t_0^m} \overset{\mathbf{r^m}}{\Longrightarrow} \mathbf{t_1^m}$ for each team member m. Additionally we have the transformation $\emptyset \overset{\mathbf{r^{m+1}}}{\Longrightarrow} \mathbf{t_1^{m+1}}$ that introduces the new team member $m+1$. Formally, we assume arbitrary many empty team members $\emptyset$ (i.e. the empty PT net without places and transitions) that are transformed* *to new members.*

The rule r has to be specialized for the interface, so that it can be used as a rule for both the mobility and the workflow layer. Therefore we use the subsequent Specialization Theorem.

Theorem 1 (Specialization Theorem [PP01])

Let $r = (L \leftarrow K \rightarrow R)$ *be a rule and* $G \overset{(r,m)}{\Longrightarrow} H$ *be a transformation with match morphism* $L \overset{m}{\rightarrow} G$*. Then* $spec(r) = (G \leftarrow D \rightarrow H)$ *is a new rule obtained from* r *by specializing the context of application via the morphism* $K \rightarrow D$*. If* $(spec(r), m') : G' \Longrightarrow H'$ *then* $(r, m \circ m') : G' \Longrightarrow H'$.

$$\begin{tikzcd}
L \arrow[d, "m"'] & K \arrow[l] \arrow[r] \arrow[d] & R \arrow[d] \\
G \arrow[d, "m'"'] & D \arrow[l] \arrow[r] \arrow[d] & H \arrow[d] \\
G' & D' \arrow[l] \arrow[r] & H'
\end{tikzcd}$$

Theorem 2 (Union Theorem for interfaces)

Given a union $G_1 +_I G_2 = G$*, the transformation* $I \overset{r}{\Longrightarrow} J$ *and the transformations* $G_1 \overset{spec(r)}{\Longrightarrow} H_1$ *and* $G_2 \overset{spec(r)}{\Longrightarrow} H_2$ *via the specialization of* r *(see Theorem 1), then we have* $G \overset{spec(r)}{\Longrightarrow} H$ *and* $H_1 +_J H_2 = H$ *so that the diagram below commutes.*

$$\begin{tikzcd}
G_1, G_2 > \arrow[r, Rightarrow, "I"] \arrow[d, Rightarrow, "{spec(r),spec(r)(=)}"'] & G \arrow[d, Rightarrow, "spec(r)"] \\
H_1, H_2 > \arrow[r, Rightarrow, "J"] & H
\end{tikzcd}$$

For the proof see [BMH06].

Theorem 3 (Consistency maintenance for interfaces)
Given a consistent layer environment $T_0 = M_0 +_I \underline{W}_0$ *with the place gluing* $\underline{W}_0 \overset{pg_0}{\rightarrow} W_0$*, the activity arrows* $\mathbf{t_0^m} \overset{\alpha_0^m}{\rightarrow} T_0$*, a transformation* $I \overset{r}{\Longrightarrow} J$ *and transformations* $M_0 \overset{spec(r)}{\Longrightarrow} M_1$*,* $W_0 \overset{spec(r)}{\Longrightarrow} W_1$*, then the transformations yield again a consistent layer environment* $T_1 = M_1 +_J \underline{W}_1$ *with the place gluing* $\underline{W}_1 \overset{pg_1}{\rightarrow} W_1$ *and the activity arrows* $\mathbf{t_1^m} \overset{\alpha_1^t}{\rightarrow} T_1$ *for each m, provided the following conditions hold:*

1. *compatibility with the place refinement, i. e. the specialization rule* $spec(r)$ *is compatible with the morphism* pg_0*,*
2. *existence of activity rules, i.e. for each m there are activity rules* $\mathbf{r^m}$ *over p and*
3. *conformance of activity rules and team member nets, i.e.* $\mathbf{t_0^m} \overset{\mathbf{r^m}}{\Longrightarrow} \mathbf{t_1^m}$ *is compatible with* $T_0 \overset{r}{\Longrightarrow} T_1$.

Proof. The activity arrows $\mathbf{t_1^m} \overset{\alpha_1^t}{\rightarrow} T_1$ and the place gluing morphism $\underline{W}_1 \overset{pg_1}{\rightarrow} W_1$ are given by Lemma 1 in [BMH06]. With the given specialization $spec(r)$ it is possible to obtain T_1 as the union of $M_1 +_J \underline{W}_1$ by using the Union Theorem for Interfaces. The result is a new consistent layer environment $T_1 = M_1 +_J \underline{W}_1$ with the place gluing $\underline{W}_1 \overset{pg_1}{\rightarrow} W_1$ and the activity arrows $\mathbf{t_1^m} \overset{\alpha_1^m}{\rightarrow} T_1$ □

3.3 Transformation of mobility and workflow layer

In [PHE+07] we obtain the teamwork net that integrates the changes induced by the transformations of mobility and workflow layer. The results for net transformations (see [EP04]) yield a variety of independence conditions for the sequential, parallel application of rules and for the compatibility with pushouts. Subsequently we develop the conditions for maintaining layer consistency based on transformations at the mobility and the workflow layer.

The main result in [PHE+07] is illustrated in Fig. 7 and states the following:

Let there be the transformations $W_0 \xRightarrow{r^W} W_1$ and $M_0 \xRightarrow{r^M} M_1$ that are *compatible with place refinement*, and provided the interface I is preserved (that is, the applications of the rules r^W and r^M are independent of I) then there is the parallel rule $r = r^W + r^M$, so that the application of r to the teamwork net T_0 yields the transformation $T_0 \xRightarrow{r} T_1$, with $T_1 = M_1 +_I \underline{W}_1$. If moreover the transformation $T_0 \xRightarrow{r} T_1$ restricted to the transformations $\mathbf{t_0^m} \xRightarrow{\mathbf{r^m}} \mathbf{t_1^m}$ for each team member $m = 1, \ldots, n$ is compatible with the activity arrows then the *existence of activity rules* ensures that for each team member the rule $r = (L \leftarrow K \rightarrow R)$ is restricted to an activity rule $\mathbf{r^m} = (\mathbf{L^m} \leftarrow \mathbf{K^m} \rightarrow \mathbf{R^m})$, where $\mathbf{K^m}$ has to be the pullback (roughly an intersection) of $\mathbf{L^m}$ and K as well as the pullback of $\mathbf{R^m}$ and K.

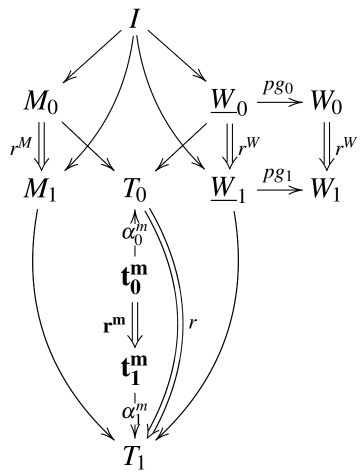

Fig. 7. Maintaining Consistency

Moreover, each activity rule $\mathbf{r^m}$ has to be the reduction of the corresponding rule r to that part being relevant for the team member m. The *conformance of activity rules and team member nets* means that $\mathbf{L^m}$ is additionally the pullback of $\mathbf{t_0^m}$ and L, and the application of an activity rule $\mathbf{r^m}$ to a team member net $\mathbf{t_0^m}$ yields the transformation $\mathbf{t_0^m} \xRightarrow{\mathbf{r^m}} \mathbf{t_1^m}$.

4 Scenario: Emergency Management

As an exemplary scenario we use archaeological disaster/recovery: after an earthquake, a team (led by a team leader) is equipped with mobile devices (laptops and PDAs) and sent to the affected area to evaluate the state of archaeological sites and the state of precarious buildings. The goal is to draw a situation map in order to schedule restructuring jobs. The team is considered as an overall MANET in which the team leader's device coordinates the other team member devices by providing suitable information (e.g. maps, sensible objects, etc.) and assigning activities. A typical cooperative process to be enacted by the team is shown in Fig. 8, where the team leader has to select a building based on previously stored details of the area while team member 1 could take some pictures of the precarious buildings. Finally, these results have to be analyzed by the team leader in order to schedule next activities. In the following we exemplary present PT nets called token nets for our scenario. As described above, Fig. 8 presents the workflow W_0 that has to be cooperatively executed by the team. The dashed lines are an additional information illustrating the relation among tasks and team members and are not a part of the PT net itself.

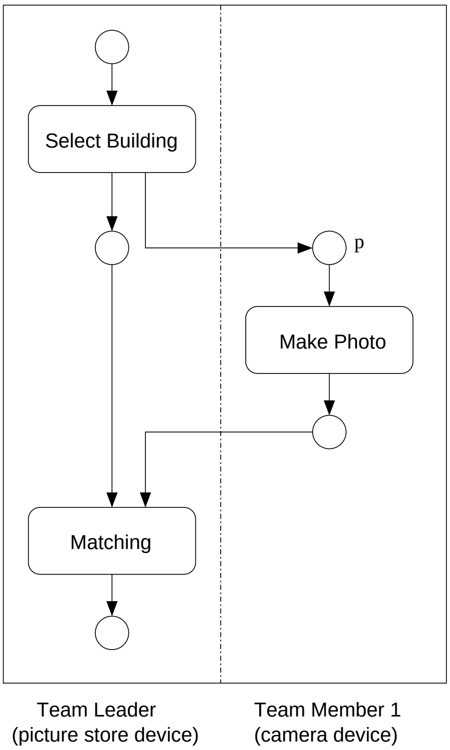

Fig. 8. Workflow W_0

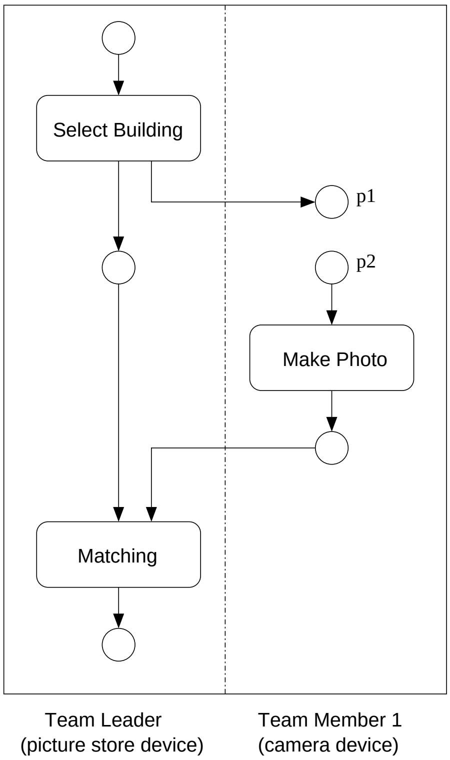

Fig. 9. Workflow $\underline{W}_0$ with splitted places

There is a corresponding workflow $\underline{W}_0$ where the place **p** is represented by two places **p1** and **p2** to integrate movement activities. In Fig. 10 the token net M_0 presents the mobility aspect of team member 1 stating that he/she has to go to the selected destination. Finally, in Fig. 11 and Fig. 12 there are two separate nets for the team layer showing the local view of each team member onto the workflow and the mobility net. This situation is a consistent layer environment as the teamwork net T_0 (see Fig. 14) is produced by gluing the workflow W_0 (see Fig. 8) and the mobility net M_0 (see Fig. 10). In more detail, the place **p** in the workflow W_0 is refined by the movement activities of team member 1. Moreover, the local view of each team member (see Fig. 11 and Fig. 12) is achieved by the activity arrow, i.e. an inclusion into the teamwork net that realizes the relation of team members to their activities. In a particular scenario the movement of the device equipped with the camera may result in a disconnection from the others.

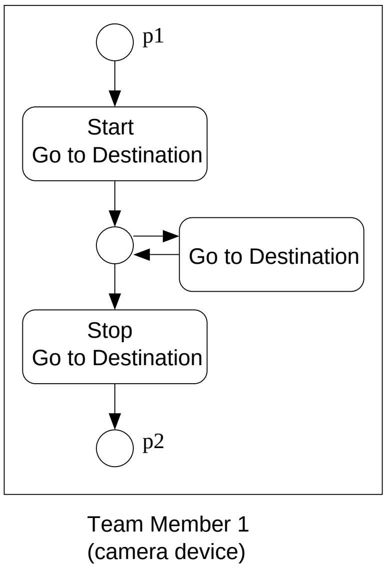

Fig. 10. Mobility net M_0

To maintain the network connectivity and ensuring a path among devices a layered architecture should be able to alert the mobility layer to introduce a possible "bridge" device (e.g., the one owned by the new team member 2) to follow the "going-out-of-range" camera device and subsequently to take up further tasks, e.g. to fill in some specific questionnaires after a visual analysis of a building. In general this may result in a change of the MANET topology. Specifically, the current mobility and workflow net and the additional PT net of team member 2 have to be transformed in order to adapt it to the evolving network topology.

We consider the change of the net structure as rule-based transformation of PT nets. This theory is inspired by graph transformation systems (e.g. [Roz97]) that were generalized to net transformation systems [EP04]. The existence of several consistency and compatibility results for net transformation systems is highly profitable for maintaining consistency of workflows in MANETs.

The basic idea behind net transformation systems is the stepwise development of PT nets by appropriate rules. Think of these rules as replacement systems, where the left-hand side of a rule is replaced by the right-hand side. A transformation from a PT net N_0 to a PT net N_1 by a rule r is denoted by $N_0 \overset{r}{\Longrightarrow} N_1$. First of all we want to change the interface net as well as the mobility and the workflow net so that a new team member is created. This is achieved by the rule r_{new} that introduces gluing points for the mobility and workflow layer.

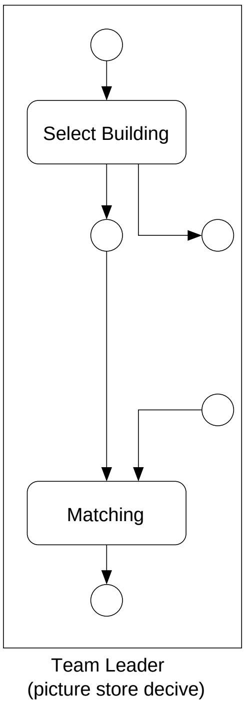

Fig. 11. PT net $\mathbf{t}_0^0$

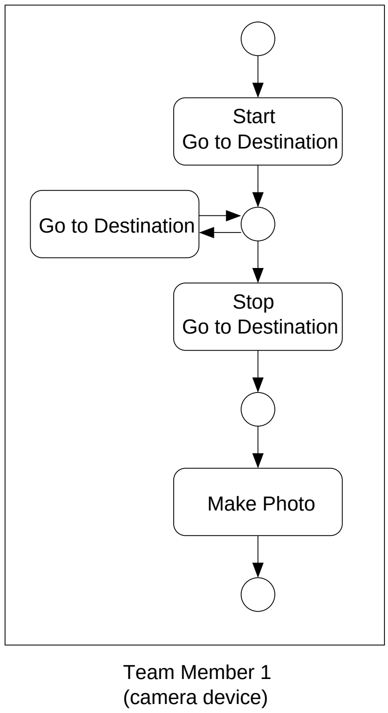

Fig. 12. PT net $\mathbf{t}_0^1$

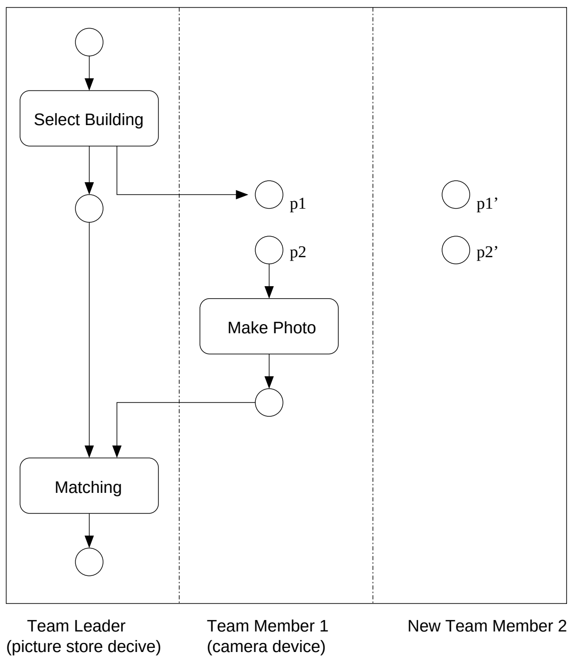

Fig. 13. Workflow $\underline{W}_1$

The specialization of the rule r_{new} is the lower row of the square in Fig 15. Its application to the nets $\underline{W}_0$, W_0 and M_0 yields the nets $\underline{W}_1$, W_1 and M_1, respectively. The gluing of workflow W_1 and mobility net M_1 yields a team work net with an additional member that has no further tasks. These can now be given by transformation that maintain consistency as defined in [PHE+07]. In our example team member 2 has to define his/her activity of making the questionnaire. This can be achieved using transformations changing the mobility and the workflow layer while maintaining consistency as introduced in [PHE+07]: The structure of the workflow W_0 in Fig. 8 is changed using the rule r_{quest} depicted in the upper row in Fig. 19 in the App. *Additional Figures* resulting in the new workflow W_1 in Fig. 19. Assume a probable disconnection while team member 1 is going to the previously selected destination.

Here the rule r_{follow} in Fig. 20 in the App. *Additional Figures* maintains the network connectivity by adding movement activities for team member 2 to follow team member 1, i.e. $M_0 \overset{r_{follow}}{\Longrightarrow} M_1$. Analogously, the net structure of the local view of team member 2 has to be adapted to include these movement activities.

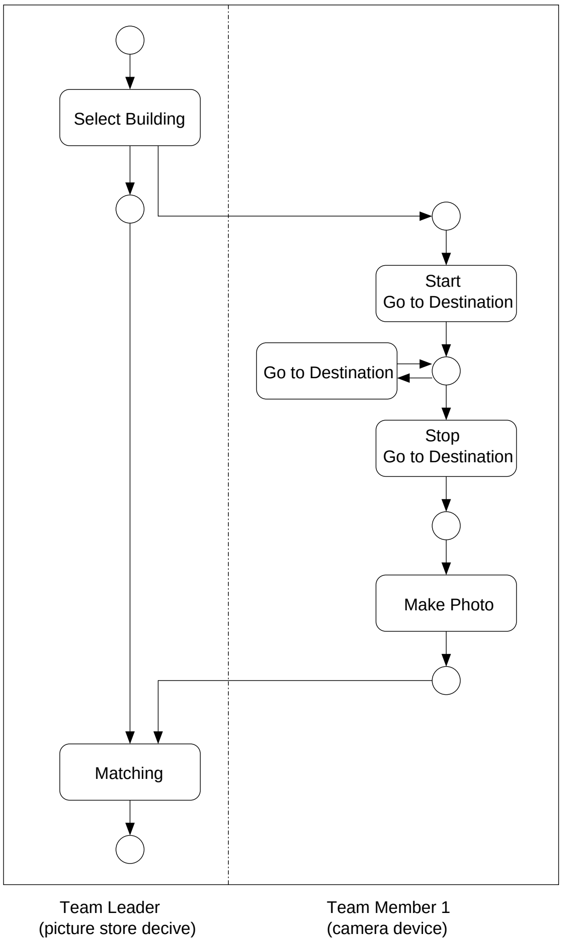

Fig. 14. Teamwork net T_0

So according to [PHE+07], we obtain a consistent layer environment provided the layer consistency conditions hold.The rule r_{quest} is compatible with place refinement because it preserves all involved places. For the same reason, the rules r_{quest} and r_{follow} are independent of the interface given by the overlapping of the workflow W_0 and the mobility net M_0. Moreover, we obtain the parallel rule r_p (see Fig. 18) consisting of both r_{photo} and r_{follow}.

The reduction to those activities of rule r_p is compatible with the transformation $T_0 \overset{r_p}{\Longrightarrow} T_1$. So, we achieve again a consistent layer environment, i.e. the teamwork net T_1 in Fig. 21 in the App. *Additional Figures* is given by the gluing of the workflow W_1 and the mobility net M_1, and there are inclusions from the restructured local views of team members to the teamwork net T_1.

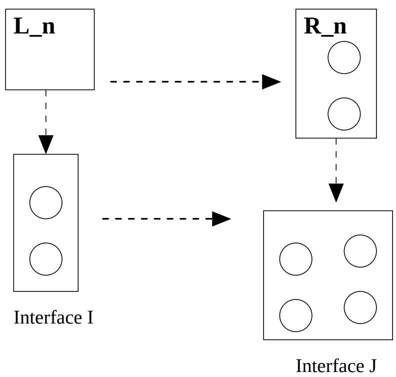

Fig. 15. Rule r_{new} in the interface and its application

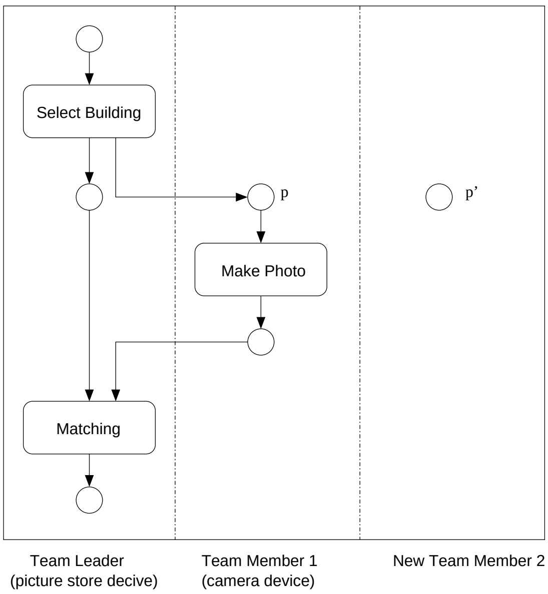

Fig. 16. Workflow W_1

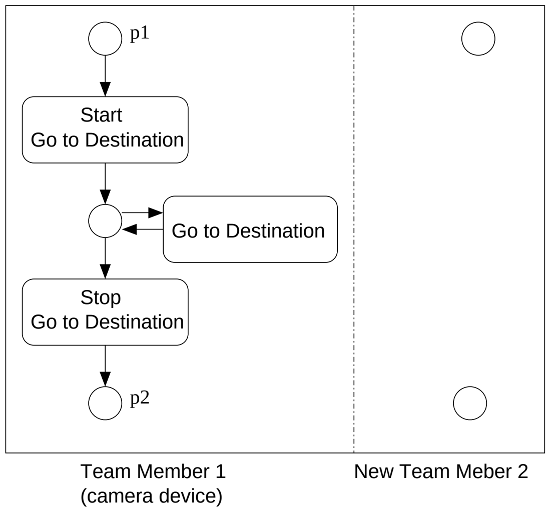

Fig. 17. Mobility net M_1

5 Conclusion

The use of a layered architecture for modeling workflows in MANETs has the advantage of separating different views with different granularity, but rises the question of consistency immediately. In [PHE+07] we have presented the notion of layer consistent environment stating that the views in the workflow layer, the mobility layer and the team layer fit together. Here, we extend this approach and allow changes in the interface. this leads to transformations in the mobility and the workflow layer that introduce new team members. Since the main modeling advantage of AHO nets is the possibility to model net transformations we have extended the maintenance means for the layered architecture for MANETs by providing an additional theorem on maintaining consistency for interface transformations.

Future research is directed at the task to ensure consistency for team members. Team work consistency concerns e.g. the consistency between each team member's activities and the complete teamwork. The team members' activities together should cover the complete team work. The categorical approach probably allows using a given topology graph to glue the team members' nets together. Then team consistency is given if this gluing corresponds to the teamwork net T. Using jointly surjective activity arrows is another possibility, so that the whole teamwork net T is covered by at least one team member. Then again, team consistency needs to be maintained during transformations in the different layers.

Another research topic are restrictions of activities. In this paper we have used arbitrary PT nets without further restrictions for modeling the layers as well as the team members' activities. Nevertheless, syntactic restrictions, e.g restricting the team members' activities to (non)-deterministic processes as well as semantic restrictions, e.g. using the approach of workflow nets in the sense of [vdAH04] for all involved nets, may be useful. The restriction of the PT-nets in the different layers requires some additional treatment. To restrict team members' activities to (non)-deterministic processes the approach to the categorical formulation of processes of (open) nets in [BCEH05] can be adopted successfully. The team members' activities are then given by a process of the teamwork net. The technical constructions we presented in this paper are compatible with the process notions, mainly since the projection of processes along injections are given by pullbacks as well.

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Additional Figures

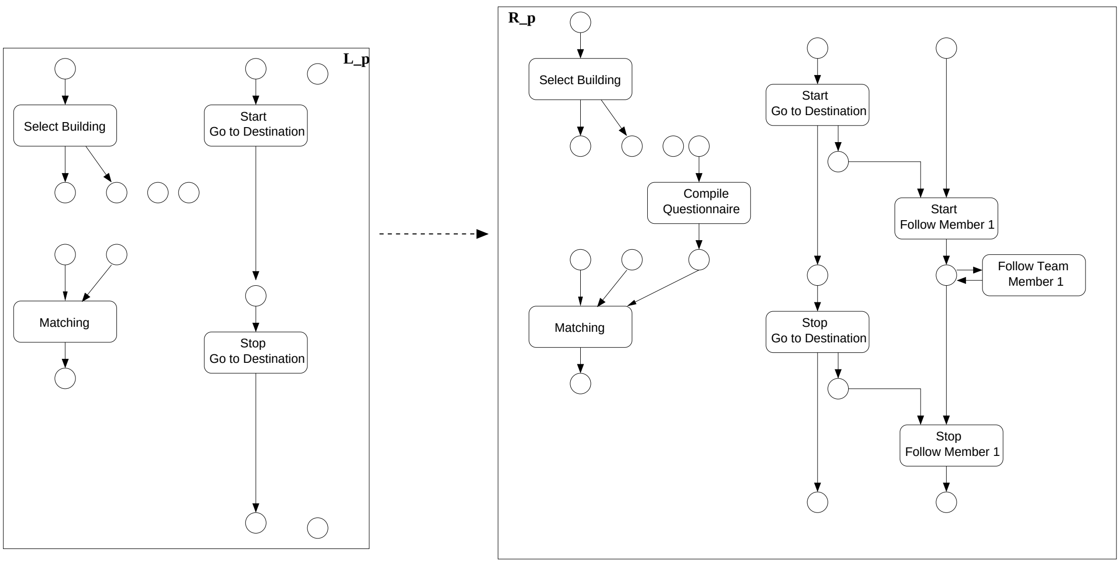

Fig. 18. Parallel rule $r_p = r_{quest} + r_{follow}$

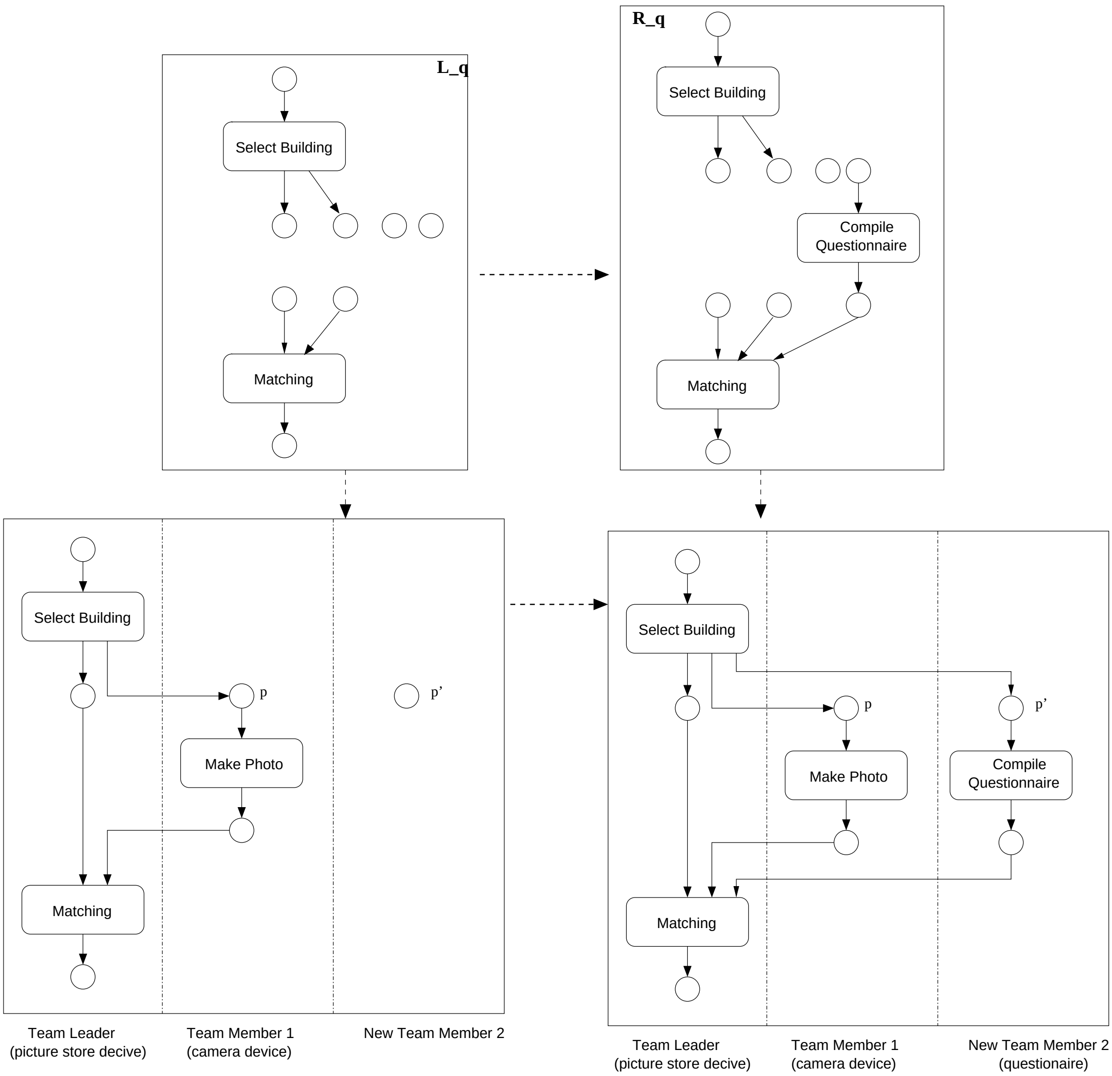

Fig. 19. Rule r_{quest} and its application

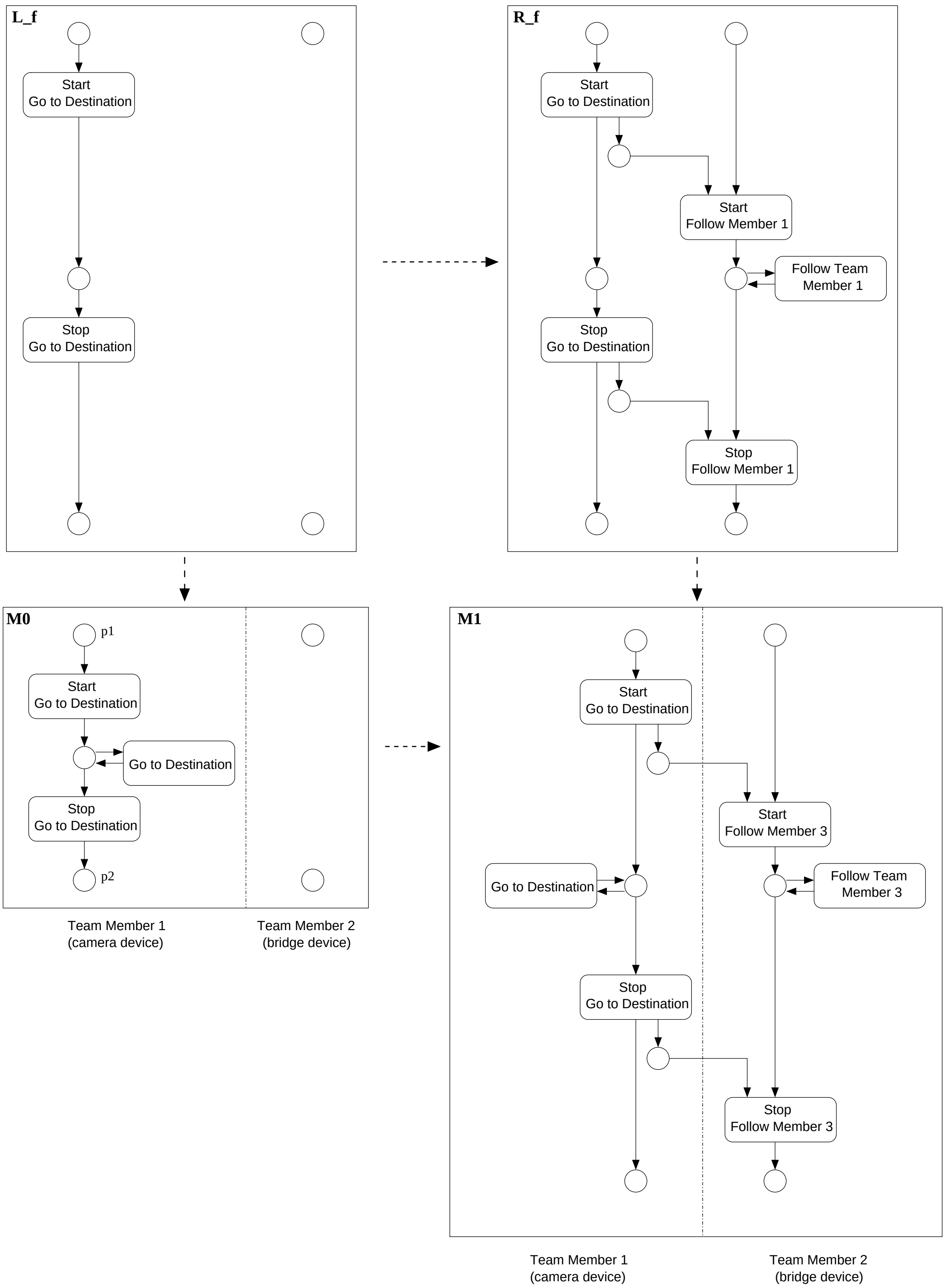

Fig. 20. Rule r_{follow} in the mobility layer and its application

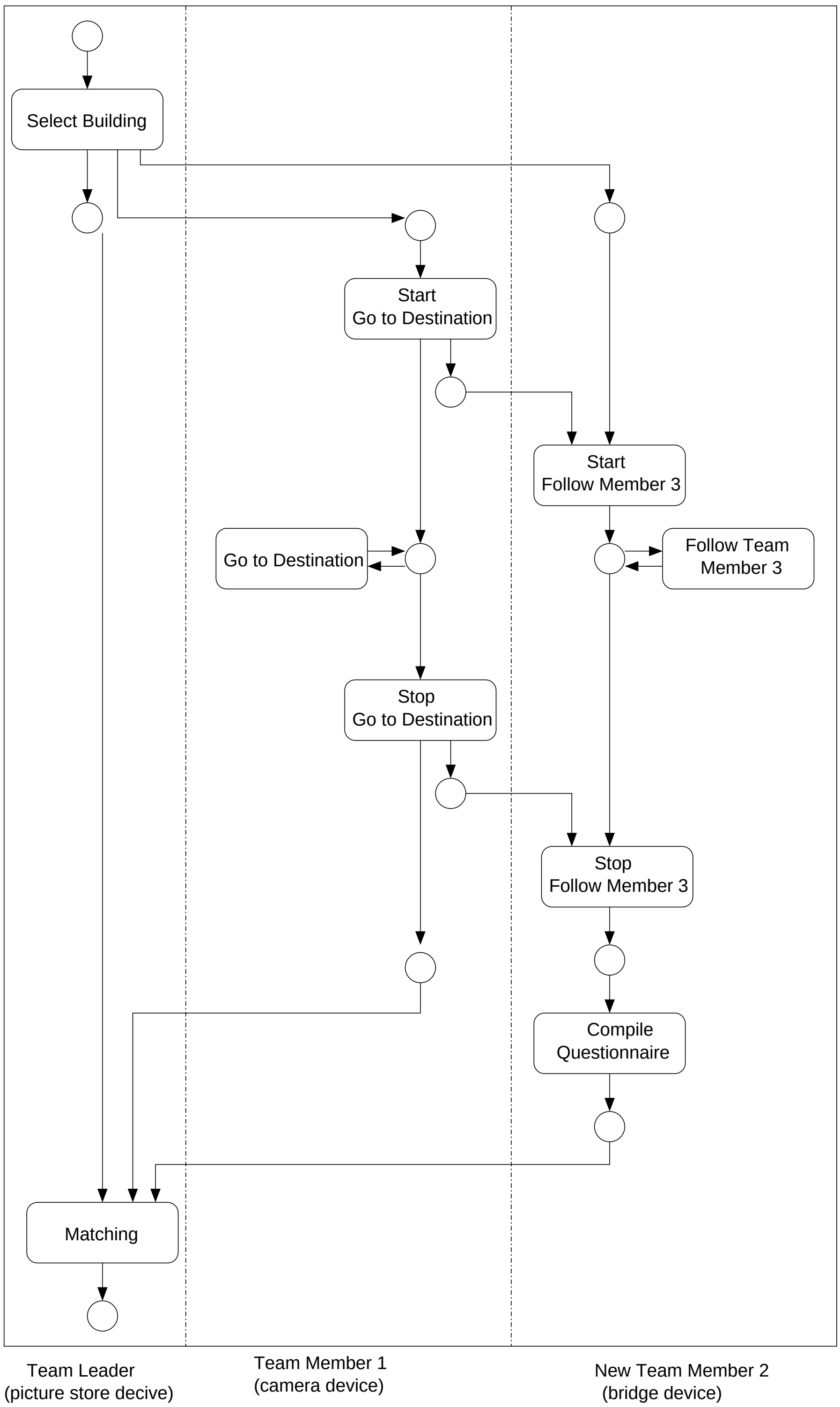

Fig. 21. Teamwork net T_1 after application of rules r_{quest} and r_{follow}

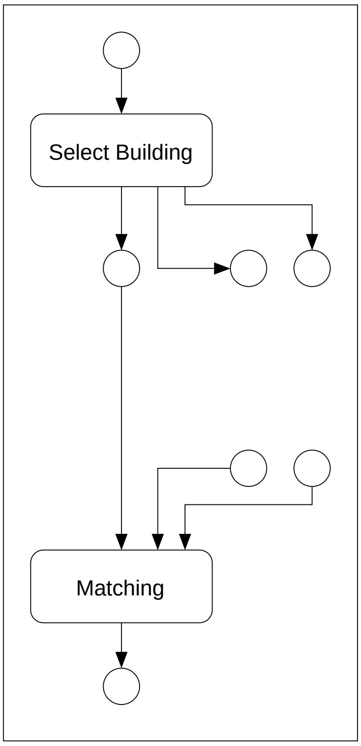

Fig. 22. PT net $\mathbf{t_1^0}$

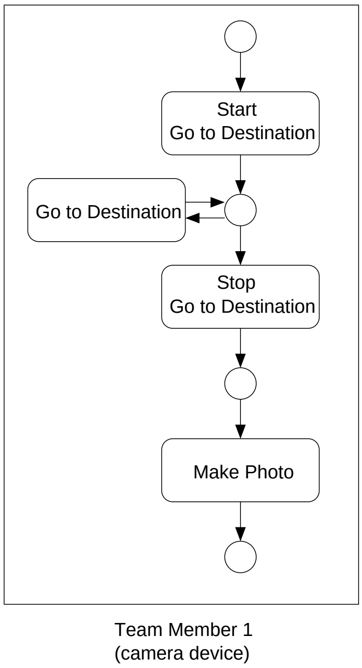

Fig. 23. PT net $\mathbf{t_1^1}$

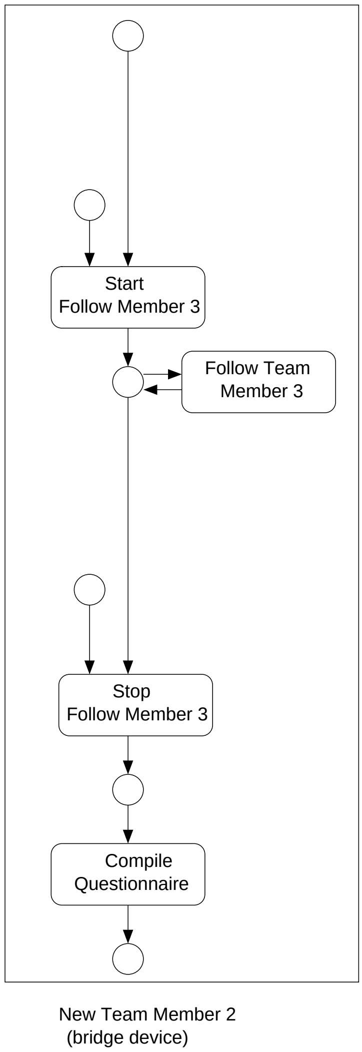

Fig. 24. PT net $\mathbf{t_1^2}$

Team member nets in team layer after rule application