Abstract- This paper discusses a class of problem, called inconsistent context, which appears due to the mobility of ad hoc nodes among multi-homed Internet domains, the ad hoc routing forwarding strategies, and the requirement of backward/forward traffic of 2-way connection, e.g., TCP, which must be transmitted through the registered Internet gateways. Solutions are then proposed, which either reduce or eliminate completely the inconsistent context problems.

Keywords- inconsistent context, Internet connectivity, MANET, Internet gateway, multi-homed domain.

I. INTRODUCTION

Attempts are in progress to connect mobile ad hoc networks (MANETs) to the Internet infrastructure to fill in the coverage gaps in the areas where the first-hop coverage (e.g., WLANs or cellular networks) is not available. In the very near future, mobile nodes will roam across multiple heterogeneous platforms while continuously maintaining session connectivity. A mobile node may connect to a WLAN, and then move into an area where the coverage from the WLAN does not exist. There, it may reconfigure itself into ad hoc mode and connect to a MANET. Essential to such seamless mobility is efficient mobility management and handover (handoff) support, as well as forwarding traffic strategies out/in the Internet. For the MANET integration with IP networks, the MANET should adapt to the network functionality within IP networks. The MANET is often seen as self-contained and is of limited size. The MANET is usually considered as the complementary to the IP network, where the Internet connectivity is extended into a MANET, making a MANET a part of the Internet [1]-[2].

The current trend in Internet mobility management is to use mobile IP (MIP) [3]-[4] for the macro-mobility, i.e., the mobility of Internet hosts among Internet domains belong to different ISPs. However, MIP tolerates high signaling overhead if there is a long distance between the foreign subnet that a mobile node moves in and its home network, as well as the ping-pong effect of mobility. To reduce this overhead, solutions can be generally classified into two approaches: micro-mobility [7] and fast handover [8]-[9]. The former uses the address of a gateway that is common to a potentially large numbers of network access points (or base stations). When a mobile host moves from one access point to another one (which is reachable through the same gateway), then there is no need to inform its home agent, and thus reducing the signaling overhead. The latter reduces delay and packet loss during the handover (handoff) by using the coupling and synchronization between IP and radio layer to predict the new subnet the mobile host will move into.

In this paper, we consider a class of problem which is subject to 2-way traffic, e.g., TCP or any real time traffic, which requires the forward and backward traffic to be fixed into the same IGW. Otherwise, the connection is terminated. This type of traffic is generated by either MANET node or Internet host, forwarded to the other via the Internet gateways, which locate between MANET and the Internet. The appearance of multiple IGWs between MANET and the Internet introduces different approaches for associating (registering) MANET nodes in one domain (subnet) to IGWs, depending on the IGW selection metrics. However, this creates the misunderstanding between which IGW a MANET node associates and which IGW forwards actually traffic for MANET node, called inconsistent context. This situation can happen on any multi-hop chains where different MANET nodes on the chain update their own views (contexts) for forwarding traffic in/out the Internet during the operation of corresponding MANET routing protocol (proactive vs. reactive vs. hybrid) [11] and IGW discovery method.

In scope of this paper, the association means a MANET node chooses an IGW for its outbound traffic to the Internet, but this IGW can be different from the IGW it registers with its home agent (for inbound traffic from the Internet), e.g., for updating to the shorter route to another IGW. As a result, this creates the inconsistent context problems as described in the subsequent sections.

This work has been fully supported by Austrian Academic Exchange (ÖAD) and EuroNGI/FGI project under the PhD research program in the Department of Telecooperation, Johannes Kepler University Linz.
II. SCENARIOS OF INCONSISTENT CONTEXT PROBLEMS

In this section, we assume that MANET mobility management uses MIPv4/MIPv6 for the macro-mobility and ad hoc routing protocol for the micro-mobility. The data traffic sent from a MANET node to an Internet host is forwarded through the Internet gateway using either the default route or the tunneling techniques [1], [5]-[6].

A. Inconsistent Context in Default Route Forwarding (Type I)

In this forwarding mode, a MANET node (MN) sends packets to the Internet, i.e., communicates with the correspondent node (CN), using the default route. Whenever it associates with an IGW, it sets its default route pointing to this IGW. The default route is used to forward data packets to the unknown destination. In the scope of the MANET, it usually means that the destination is not in the same MANET domain and can be located in the Internet, thus the data packet is forwarded to the IGW, where it is dropped if the destination is unreachable or continued forwarding to the Internet if the destination is reachable via IGW. MANET node (MN) (5)’s routing table using default route in Fig.1 shows an example, where MN (4) is used as the next-hop to the associated IGW_1.

The problem with this default route setting is that MN (5) does not know its current associated IGW. Thus, the inconsistent context on sending packets from MN (5) to the Internet (e.g. via IGW_2) and receiving packets from CN to MN (5) (e.g. via IGW_1) can terminate the 2-way connection (e.g. TCP). The next section shows an advanced setting to reduce this effect.

B. Inconsistent Context in Default Route Forwarding (Type II)

In this forwarding mode, a MANET node adds an additional entry into its routing table for the default route, indicating the current IGW that this MANET node associates. Fig. 1 shows again the MN (5)’s routing table using extended default route.

With this advanced setting, the ambiguous IGW association of MANET node is solved. However, an additional cost on storage and access time for the additional entry is introduced. Moreover, the inconsistent context problems are still existed in other scenarios, which are presented in the next section.

C. Inconsistent Context in Default Route Forwarding (Type III)

Different scenarios indicating the inconsistent context are analyzed in this section, which can be dependent on the MANET routing protocol [11] and IGW discovery method (proactive vs. reactive vs. hybrid) [1].

Scenario I:

A MANET node updates a shorter route to another IGW without re-registering the new IGW with its home agent (HA), and/or the foreign agent (FA) as well as the network address translation (NAT) device located in the visiting MANET domain.

Fig. 1 shows an example, where MN (1) moves from its home network to the new MANET domain, registering to its HA via IGW_2 through MN (3) as the next-hop to the IGW2. The distance from MN (1) to IGW_2 is 3 hops. Later, MN (1) finds a shorter route to the Internet via IGW_1. MN (1) chooses MN (2) as the next-hop to the IGW_1 and the hop-count is 2. In this scenario, traffic from MN (1) to the CN is forwarded via IGW_1. However, traffic from the CN to MN (1) is still forwarded via IGW_2 since it is registered by MN (1) to MN (1)’s HA. This creates the inconsistent context.

Scenario II:

A MANET node associated with an IGW (e.g., IGW_1) forwards agent/router advertisement packet for another IGW (e.g., IGW_2). As a result, its downstream nodes can associate to the IGW_2 using it as the next-hop. However, the traffic is actually forwarded through IGW_1.

As an example, in Fig. 1, suppose that MN (4) is currently associates with IGW_1 and MN (5) is not associated with any IGWs. The IGW will broadcast periodically its agent/router advertisement packets. When MN (4) receives IGW_2 agent/router advertisement packets, MN (5) will set MN (4) as the next-hop to IGW_2 in its default route, if MN (4) continues forwarding IGW_2’s agent/router advertisement packets. However, whenever the traffic to CN is generated by MN (5), and then forwarded to IGW_2 via MN (4), this traffic is actually forwarded via IGW_1 by MN (4). This creates the inconsistent context.
Note that the decision of MN (4) whether or not to continue forwarding other IGWs packets (e.g. agent/router advertisement) is depending on the corresponding operation and implementation of MANET routing protocol and IGW discovery method [1].

Scenario III:
A MANET node looses its association to the current IGW (e.g. a detection of link broken) and re-associates to another IGW. As a result, traffic to Internet from its downstream nodes choosing it as the next-hop to the current IGW will be forwarded via another IGW instead.

As an example, in Fig. 1, suppose MN (3) chooses MN (4) as its next-hop to the IGW_1 and MN (4) is currently associated to the IGW_1. Later, if the link between MN (4) and IGW_1 is broken, MN (4) re-associates to IGW_2. Thus, traffic to the Internet from MN (3) will be forwarded via IGW_2, though MN (3) thinks it is forwarded via IGW_1. This creates the inconsistent context.

III. PROPOSED SOLUTIONS

A. Solutions on Reducing Inconsistent Context of Using Default Route

Solution for Scenario I:
A MANET node is not allowed to update its shorter route to another IGW, unless its current transmissions on any 2-way connections to the Internet hosts are finished, and it has already re-registered this new IGW with its home agent. This re-registration can be prepared in advance, e.g. during the data transmissions on the current connections via the old IGW.

Clearly, this rule removes completely the inconsistent context in Scenario I since the inbound/outbound traffic to/from Internet is always forwarded via the same IGW. However, its disadvantage is that intra-MANET route from the source MANET node to the registered IGW is not an optimal one, e.g. the shortest route.

This rule also reduces the inconsistent context in Scenario II and Scenario III. The reason is that, the less changing on the IGW re-association of MANET nodes, the less inconsistent context problems appear on their downstream MANET nodes.

Solution for Scenario II:
On proactive IGW discovery, a MANET node that does not register to any IGW is allowed to re-broadcast the received agent/router advertisement if it decides to register with this IGW. Otherwise, the re-broadcasting of agent/router advertisement is prohibited.

On re-active IGW discovery, a MANET node is allowed to generate/forward an agent/router advertisement in one of the following three cases:

- It does not register to any IGW, registering it to the IGW of which the agent/router advertisement it receives, then forwarding the agent/router advertisement to the source MANET node.
- It has already registered to an IGW, receiving the agent/router advertisement generating by the same IGW, then forwarding this agent/router advertisement to the source MANET node.
- It has already registered to an IGW, receiving the agent/router solicitation from the source MANET node, generating itself an agent/router advertisement to the source MANET node.

On hybrid IGW discovery, the above rules are applied whenever an agent/router advertisement or an agent/router solicitation is received.

Clearly, the above rules ensure that all the MANET nodes on the chain from any source MANET node to their registered IGWs uses the same IGW for inbound/outbound traffic to/from the Internet.

However, on the proactive IGW discovery, the applied rule creates non-overlapped MANET domains, each domain associates to only one IGW. Thus, it does not take the advantage of using multiple IGWs for load balancing and fault-tolerance. Moreover, there can be the appearance of orphan MANET nodes due to the collision or high mobility.

On reactive or hybrid IGW discovery, the generation of agent/router advertisement of an IGW or an immediate MANET node, called gratuitous agent/router advertisement or proxy route reply (RREP) if this agent/router advertisement is piggybacked on RREP of MANET reactive routing protocol, to the source MANET introduces non-optimal route. This happens whenever the destination is located in the same MANET domain of the source MANET node, and the source MANET node receives a proxy RREP before the normal RREP sent by the destination, e.g. due to the collision or longer hop-count. This problem can be further reduced by the use of the destination sequence number, in which this field on the proxy RREP packet is always set to a small value, e.g. “0”. Thus, when the source MANET node receives the RREP sent by the destination later, it will updates the host route to the destination instead of the default route via the IGW, since the destination sequence number sent by the destination is greater than that of proxy RREP sent by the IGW.

Solution for Scenario III:
There should be a mechanism for the MANET node detected the broken link, sending this information to its downstream MANET nodes so that these MANET nodes can re-register their new IGWs with their home agents. This mechanism is usually MANET routing protocol dependent.

As an example, in ad-hoc on-demand distance-vector (AODV) routing [10], a MANET node keeps a list of other neighbor MANET nodes using it as the next-hop to a set of destinations, called precursor list. Whenever this MANET
node detects a broken link to any destination, it searches its precursor list for that destination and sends a route error (RERR) to all the nodes on this list. This process is propagated to the MANET nodes in its precursor list.

In the scope of this scenario, a MANET node detecting a broken link to its registered IGW will integrate this information to the RERR and send it to all nodes in its precursor list. However, to reduce also the inconsistent context in the Scenario II, the detected MANET node also sends the RERR to all the precursor lists associated to all IGWs as the destinations. This is because some MANET nodes can be associated with an IGW, but their traffic can be forwarded to another IGW instead.

B. Solutions on Removing Inconsistent Context Using Tunneling

Clearly, on IGW forwarding strategies using default route between a MANET domain and the Internet connecting through multiple IGWs, the inconsistent context is always a problem. This is because the traffic from the MANET to the Internet and the returned traffic can be forwarded through different IGWs, taking to the termination of 2-way connections.

With the described solutions on the previous section, the problems on default route are reduced. However, depending on the implementation of MANET routing protocol, the IGW discovery (whether they are implemented independently or dependently), there can be the appearance of another scenarios of inconsistent context. Thus, it is the purpose of this section to introduce another approach to remove completely the effect of inconsistent context.

The idea is that a MANET node is always sent its outbound traffic to the Internet via its registered IGW, irrespective its immediate MANET nodes updating the shorter routes to other IGWs. This is achieved via the use of tunneling, e.g. IP-in-IP tunneling [6]. In this scheme, the source MANET node encapsulates the original IP packet to another IP packet, in which its registered IGW is the destination IP address in the outer IP header. The encapsulated IP packet is then forwarded to its registered IGW using the MANET routing protocol. When the encapsulated IP packet arrives to the IGW, it is decapsulated and the inner original IP packet is forwarded to the destination Internet host by the IGW.

Fig. 2 shows an example, where an IP packet to the Internet from the source MANET node MN (1) is first tunneled (encapsulated) to its registered IGW_2, then it is decapsulated and the original IP packet is forwarded to the CN. In the reversed direction (using tunneling through MN (1)’s HA in this scenario), CN send its packet to the MN (1) home address via MN (1)’s HA, where the packet is encapsulated and forwarded to MN (1)’s FA (IGW_2). At the IGW_2, this packet is decapsulated, then encapsulated and forwarded to the MN (1).

With the tunneling, the inconsistent context problems are completely removed. However, an additional cost of adding an outer IP header is introduced.

IV. CONCLUSIONS

This paper shows solutions to reduce or completely remove a class of problem called inconsistent context. This problem style is mainly due to the ad hoc forwarding strategies through Internet gateways, using either default route or tunneling techniques. Our future works will be the measurements of data packet delivery ratio under different scenarios, using our proposed enhancements.

REFERENCES