

## IMPLEMENTING MOBILE AD HOC NETWORKING (MANET) OVER LEGACY TACTICAL RADIO LINKS

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### ABSTRACT

*Mobile Ad Hoc Networking (MANET) is a key technology enabler in the tactical communication domain for the Network Centric Warfare.[1] A self-forming, self-healing, infrastructure-less network consisting of mobile nodes is very attractive for beyond line of sight (BLOS) voice and data range extension as well as tactical networking applications in general. Current research and development mostly focus on implementing MANET over new wideband data waveforms. However, a large number of currently fielded tactical radios and the next generation software defined radios (SDR) support various legacy tactical radio waveforms. A mobile ad hoc network over such legacy tactical radio links not only provides war fighters mission critical networking applications such as Situational Awareness and short payload messaging, the MANET nodes can also support voice and legacy data interoperation with the existing fielded legacy radios. Furthermore, the small spectrum footprint of current narrowband tactical radio waveforms can be complementary to the new wideband data waveforms for providing networking access in a spectrum constrained environment. This paper first describes the networking usage requirements for MANET over legacy narrowband tactical waveforms. Next, the common characteristics of legacy tactical radio waveforms and the implications of such characteristics for the MANET implementation are discussed. Then an actual MANET implementation over a legacy tactical radio waveform on a SDR is presented with the results of actual field tests. Finally, several improvements to this implementation are proposed.*

### I. INTRODUCTION

A MANET is a dynamic and self configuring network consisting of a collection of mobile nodes connected by wireless links. Generally, a MANET does not need a network infrastructure such as a base station or an access point to function correctly. Each node in a MANET can serve as both host and router. The forming and adaptation of the network topology and routing are performed by the nodes in the MANET in a distributed fashion.

The infrastructure-less, self-forming, and self-healing networking properties make MANET ideally suited for tactical networking applications. However, most of the effort in this area has been directed toward implementing MANET over wideband high-speed data waveforms, such as the Soldier Radio Waveform (SRW) and Wideband Networking Waveform (WNW). [2] Currently, there are tens of thousands of legacy tactical radios widely deployed that support legacy narrowband tactical waveforms such as SINGGARS, VHF/UHF Line of Sight (LOS) and HAVEQUICK I/II waveforms. Voice and data interoperability with those radios and waveforms is essential for the effective transition to MANET technology in the battlefield. Implementing MANET over legacy waveforms enables the MANET nodes to interoperate with existing radios in legacy voice and data modes while at the same time providing networking applications to fill a critical operational gap and obtain the benefits of MANET in tactical operations, such as range extension for data and voice. In addition, the large bandwidth required by the newer high speed wideband data waveforms might not be available to all users in all locations at all times due to spectrum limitations. A MANET over legacy narrowband VHF/UHF tactical waveforms can provide a useful complement to the high data rate wideband networks in supporting mission critical applications, such as Situational Awareness (SA) and short payload messaging, in addition to the range extension benefits for data and voice communications.

### II. USER REQUIREMENTS ANALYSIS

In order to effectively design and implement a MANET over legacy tactical radio waveforms, the user requirements for such a network, including types of applications, payload characteristics, node mobility and node density are discussed in this section. The implications of those requirements for network design issues such as routing architecture, topology control and quality of service support are also analyzed.

## II.1 Networking Applications

Most of the legacy tactical waveforms have a low bit rate physical layer. Since the physical layer limits the overall throughput, the networking applications running over legacy tactical waveforms must require low data rates as well. Fortunately, two of the most effective and essential networking applications, Situational Awareness and short payload messaging, both require relatively low data rates.

**Situational Awareness** generally requires the transmission of location and other SA information over a tactical network. The SA information do not demand high data rates and are relatively latency tolerant. Furthermore, a large portion of traditional tactical communications involves verbally reporting position, location, and tracking (PLT) information to other team members. Replacing verbal PLT with an automatic Situational Awareness application significantly reduces the amount of voice communications; improves the accuracy of the PLT information; and effectively increases the available bandwidth for other applications. As a result, SA is an ideal application for a MANET implemented using legacy tactical waveforms.

Two types of SA scenarios can be targeted. One is the situational awareness within a relatively small tactical team. Each team member needs to be aware of other team members' locations and status. This case indicates the importance of supporting local multicast/broadcast traffic. Another scenario is to send location and status information through reach-back channels to command and control centers. This configuration suggests the implementation of a gateway capability.

**Short Payload Messaging** is another low data rate but critical and effective tactical networking application. Similar to the Short Message Service (SMS) for cell phones, short payload messages through small battlefield ad hoc networks linking various teams and team members is an ideal way for silent, concise and accurate communications. The short messages can be free-hand input by users or predefined as part of mission profile.

## II.2 Payload Characteristics

The needs of tactical operations lead to some unique traffic characteristics as described below.

**Voice/Data Simultaneity:** Voice support in networking mode is essential to tactical radio users. Any implementation of networking capabilities over legacy tactical radio waveforms must not prevent point-to-point voice communication with other legacy radios running the same waveform. For direct point-to-point voice

communication between MANET nodes and with legacy radios, voice communications can be supported by legacy waveforms in non-packetized mode. To support multi-hop voice (voice range extension), the voice generally needs to be packetized, and the number of hops needs to be limited to maintain good voice quality. Voice and data transmission can share the access to RF medium arbitrated by a MAC protocol, such as CSMA MAC. Access priority is usually given to the voice traffic.

**Multicasting/Broadcasting:** Due to the team oriented nature of the tactical operations, group communication in the form of multicasting and broadcasting is very important for tactical MANET.

**Traffic Periodicity:** One important characteristic for SA traffic is the periodicity of the SA update messages. This periodicity can be exploited when combined with a periodical MANET control message in the context of legacy waveform, as discussed in III.2.

## II.3 Network Topology and Routing

The requirements of tactical operations, the use cases, and the mobility and density of the nodes all affect the network topology, implementation and routing architecture. Figure 1 illustrates an example MANET that provides multi-hop Situational Awareness and short payload messaging between three small tactical teams:

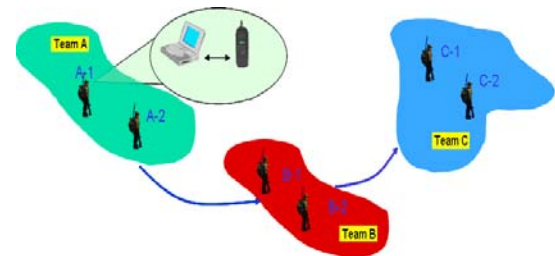


Figure 1- Tactical MANET Configuration Example

**Node Mobility and Density:** In a tactical edge MANET operation for dismounted soldiers, the relative node mobility compared to radio range is low to moderate. The number of nodes in a MANET is usually less than 16. This indicates relatively slow topology change and small number of routing hops.

**Gateway Support:** Multiple MANETs can be formed over different RF channels and linked together by gateways. Gateways can also provide SATCOM reach back or fixed network connectivity for a tactical MANET. Depending on the network operational requirements, there are three network configurations in terms of gateways:

- **Stand-alone Network:** A MANET is formed between radio nodes over same channel and waveform with no gateway to another network.
- **Stub Network:** Only one gateway, the default gateway, connects the stub MANET to another MANET or fixed network. For example, a default gateway may provide SATCOM reach back for the stub MANET. Gateway routing is simple for a stub network as only the default gateway needs to be defined and propagated along with the standard MANET routing information.
- **Transit Network:** A transit network connects to multiple external networks (MANET or fixed network) through multiple gateways. Gateway routing is complex for a transit network because the external routing information needs to be combined and propagated with internal MANET routing information.

**Radio Embedded Routing:** For optimum performance, the routing functionality needs to be embedded in the radio so that the MANET can be formed and operational without the need to attach a PC/PDA to each radio node.

#### II.4 Quality of Service and Reliable Delivery

The periodic location update messages of a Situational Awareness application are relatively delay tolerant. Due to the periodicity of the traffic, a reliable delivery mechanism such as ARQ is not needed.

Short payload messages are more delay sensitive than SA updates, but generally can tolerate several seconds of transport delay. Reliable delivery is a must for short payload messaging.

#### II.5 Networking CONOP Template

Table 1 summarizes the network parameters for SA and short messaging over narrowband tactical waveforms:

Table 1- SA and Short Messaging Networking Parameters

Application Payload	Payload Type	PLT (position, location and tracking) & short messages
	Payload Size	1 ~ 200 bytes
	Payload Rate	SA: Periodical transmission <1 message/15 second/node
	Voice Support	Voice with data
	Dest. Type	Unicast, multicast, broadcast
Network Topology & Routing	# of nodes	< 32, typically ~16
	Coverage area	Range extension ~ 10 miles
	Gateway	Stand-alone, stub or transit
	Mobility	Low
QoS	Latency	Near real time. < 15 seconds
	Reliable Delivery	No for PLT message
		Yes for short messaging and chat

### III. RADIO LINK CHARACTERISTICS AND MAC LAYER PERFORMANCE

Most of the legacy VHF and UHF tactical radio waveforms were initially designed for tactical voice communications with point-to-point data link capabilities added later. Unlike the commercial wireless networks, there is no infrastructure such as a base station to assist timing synchronization and channel acquisition. This infrastructure-less, point-to-point legacy heritage in tactical voice communications has resulted in some unique characteristics, including slow Rx/Tx turnaround time, large transmission overhead and low data rate. The effects of such radio link characteristics have been extensively studied for CSMA MAC [3]. Although simple, CSMA has lower control overhead compared to other MAC protocols and is especially well-suited for very small data packets as discussed in section IV. Simulations were performed to analyze the impact of such characteristics to the MANET MAC layer performance, with the results discussed below:

#### III.1 Rx/Tx Turnaround Time

Half duplex legacy tactical radios and waveforms typically have a relatively long delay when transitioning from Rx state to Tx state.

For a CSMA Medium Access Control (MAC), the Rx-Tx turnaround time is defined as the time between when the CSMA algorithm commits to transmit and when the actual RF signal is present over the air. The Rx-Tx turnaround time is the CSMA blind time during which a neighboring CSMA node, seeing the medium is still idle, can independently decide to commit to transmission, causing a collision with the other node. Increased Rx-Tx turnaround time leads to increased collision probability.

The simulation results in Figures 2 and 3 illustrate the impact of Rx/Tx turnaround time to the link throughput:

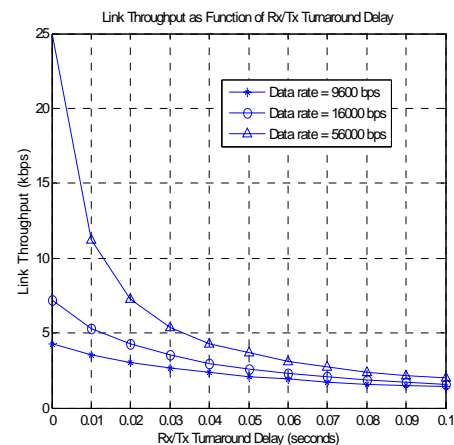


Figure 2- Throughput vs. Rx/Tx Turnaround Time (Simulated result for 160 bytes packet size)

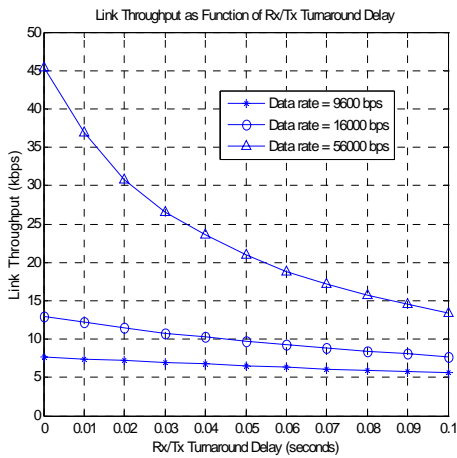


Figure 3 - Throughput vs. Rx/Tx Turnaround Time  
(Simulated result for 1500 bytes packet size)

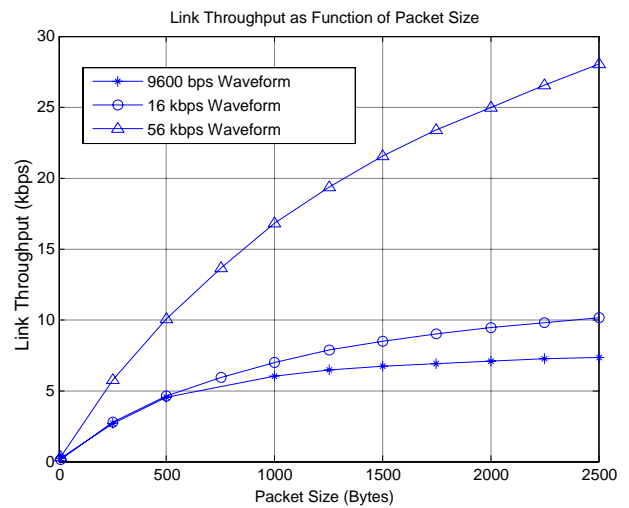


Figure 4 - Simulated Link Throughput vs. Packet Size

From the above figures it can be observed that:

- Long Rx/Tx turnaround time can cause significant throughput reduction, especially for small size packets as shown in Figure 2. This effect is due to the increased collisions as a result of larger CSMA blind time.
- Reducing Rx/Tx turnaround time has the same effect as increasing link capacity, especially for small packet size. For example, for a 56 kbps radio link with 50 ms turnaround time, the simulated throughput for 160 byte packets is 3.5 kbps. The same throughput can be achieved using a 9.6 kbps radio link with 10 ms Rx/Tx turnaround time.
- The advantage of a higher link data rate is only evident for large payload applications such as file transfer, or for small Rx/Tx turnaround time.

### III.2 Per Packet Transmission Overhead

For half duplex point-to-point radio links, each time a packet is transmitted, overhead is incurred in the form of waveform preamble for modulation synchronization and acquisition and other header information. In long transmissions, such as voice and legacy synchronous data transfer, this overhead percentage is relatively small. However, for SA and short payload messaging applications, the payload packet size is generally small and the overhead percentage is large.

The following simulation results (Figure 4) illustrate the impact of packet size to the link throughput. The simulation model assumes 50 ms Rx/Tx turnaround time.

The following observations are made from the simulations:

- Large preamble size has significant impact on link throughput for small packet applications regardless of the data rate.
- As packet size increases, the effective link throughput is increased due to the reduced the percentage of overhead to data. This observation suggests packing multiple smaller packets into a single packet to improve throughput.

To reduce the overhead rate it is advantageous to **concatenate multiple small packets into a single large transmission burst**. For periodic packet transmissions and delay tolerant applications, buffering up the packets to be transmitted and concatenating them into a single long transmission burst can greatly increase the network efficiency. For example, in a proactive link state routing protocol, there are periodic Hello packets for neighbor discovery and periodic link state packets. In addition, for SA applications, there will be periodic GPS location update packets. To increase networking efficiency, we can define the periodic timer of the Hello packet (used for neighbor discovery by the proactive MANET routing protocols) to be 10 seconds, the link state packet periodic timer to be 20 seconds, and the GPS update packet periodic timer to be 20 seconds. In this way there will be three packets to be transmitted every 20 seconds. These three packets can be combined into one single transmission to share the burden of a single transmission overhead. This packet concatenation technique mitigates the negative impact of large per-transmission overhead of legacy tactical radio waveforms.

### III.3 Low Physical Layer Data Rate

Even though the most cited reason for not being able to support networking, especially mobile ad hoc networking, over legacy tactical radio waveforms is the relatively low physical layer data rate, our analysis and experience showed that low data rate is not the main limiting factor in supporting MANET.

A common myth about the waveform data rate is that when doubling the physical waveform raw bit rate, the network throughput is doubled. This is not correct since the network throughput may be dominated by other factors such as Rx-Tx turnaround time and physical preamble size, as described in III.1 and III.2. In other words, the relationship between the physical layer waveform data rate and the network throughput is not linear.

The following simulation results (Figures 5 and 6) illustrate the non-linear relationship between the link throughput and the raw waveform bit rate for both small and large packet applications.

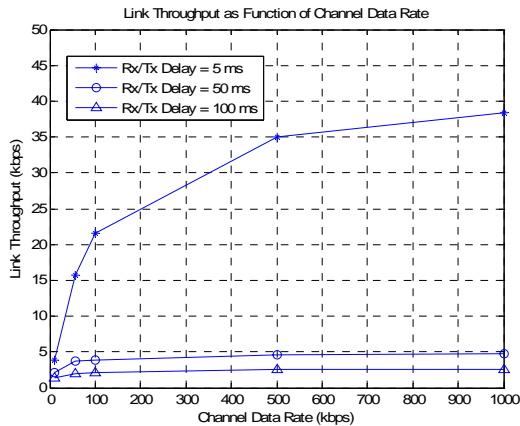


Figure 5 - Link Throughput vs. Waveform Data Rate Preamble = 160 bytes, Packet size = 160 bytes

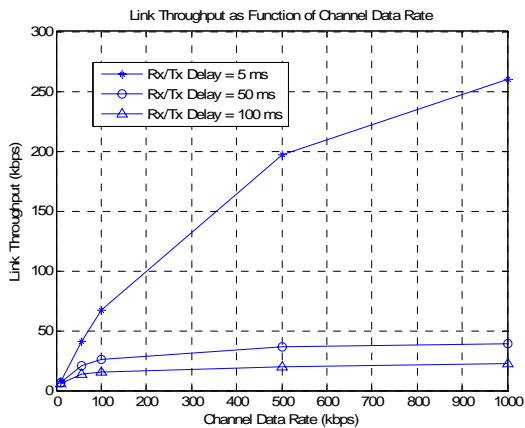


Figure 6 - Link Throughput vs. Waveform Data Rate Preamble = 160 bytes, Packet size = 1500 bytes

Following observations are made from the simulation results:

- Link throughput is not a linear function of raw bit rate of the waveform, i.e. doubling the waveform bit rate does not double the throughput. The non-linearity is more significant for small packet size applications than for large packet size applications.
- For small packet size applications such as SA and short payload messaging, simulation shows that the link throughput is mainly determined by Rx/Tx turnaround time, not waveform bit rate.
- For large packet size applications, the link throughput increases more proportionally with the increase of waveform data rate, especially when the Rx/Tx turnaround time is small.
- Higher data rate waveforms can enhance the performance of large packet size networking applications such as file transfer but not significantly enhance the performance of small packet size applications such as SA and short payload messaging.

## IV. IMPLEMENTATION AND TEST RESULTS

To demonstrate the feasibility and effectiveness of mobile ad hoc networking over legacy tactical radio links, a MANET was implemented over an existing legacy tactical radio waveform to support several tactical networking applications. The following describes the design choices and testing results of this implementation.

### IV.1 Design Choices

**PHY Layer:** SINCGARS Single Channel (SC) Enhanced Data Mode (EDM) at 9600 bps was chosen as the physical layer for this MANET. This waveform is chosen for the following reasons:

- SINCGARS is the most widely used tactical radio communication waveform on the battlefield.
- A MANET over SINCGARS supports voice and legacy data interoperability with currently deployed SINCGARS radios while at the same time providing advanced networking capabilities.

**MAC Layer:** Though many asynchronous and synchronous medium access control schemes exist, their complex control mechanism and the associated control packet overhead make them not suitable to support very short packets for SA and short payload messaging application. The large preamble overhead of legacy tactical waveforms further increases the cost of control packet exchange. For example, small RTS/CTS control packets

still carry large preambles, which offset any collision reduction gain. Therefore, a Carrier Sense Multiple Access (CSMA) was used as the MAC layer. The slot size and carrier sensing method were optimized based on the simulation and test results.

To further increase the efficiency of the MAC layer, periodicity of proactive routing control traffic and the SA update traffic were exploited so that multiple packets could be concatenated into a single transmission, reducing overhead. Each packet maintains a separate CRC.

**Radio Embedded Routing:** Before choosing a routing protocol, a determination needs to be made regarding where the routing capabilities reside. Even though MANET protocols can be easily implemented on a laptop PC/PDA attached to a radio modem, the following drawbacks prevent this configuration from being a viable solution for tactical networking:

- Each radio node needs to have a PC/PDA attached in order to form the MANET.
- Routing via a PC/PDA vs. routing embedded in the radio itself adds significant latency, especially for intermediate nodes of multi-hop communications.
- PC/PDA has shorter battery life, lower reliability and less ruggedization than a tactical radio.
- Extra equipment weight and cost associated with attaching PC/PDA to each radio node.

For above listed reasons, the radio embedded routing approach was chosen and a MANET routing stack was implemented on the radio platform instead of on external data terminals such as laptops or PDAs.

The proactive mode of Scientific Research Corporation's MobileRoute® product was used for the routing protocol. MobileRoute's proactive protocol is a QoS-enhanced, link state routing protocol similar to the Optimized Link State Routing (OLSR) protocol. For the initial field testing, best effort routing was utilized.

**Transport Layer (TCP versus UDP):** While reliable transmission is important for certain applications, the transmission control protocol (TCP) is not well-suited as the transport layer for MANETs. [4] TCP was designed for wired networks with relatively low latency and low bit error rates. When a packet is lost, TCP assumes the packet was lost due to congestion and immediately throttles back the throughput by reducing the transmit window size to 1. TCP then slowly increases the window size over time as packets are successfully transmitted.

Contrary to wired networks, MANETs are characterized by wireless links with high bit error rates and frequent link breakages. As a result, the User Datagram Protocol (UDP) is typically the transport layer for MANETs. Since UDP is unreliable, applications requiring reliable transport implement their own reliable transport protocol at the application layer. For delay tolerant applications, the automatic repeat request (ARQ) protocol is often used. For real-time applications such as voice, proactively transmitting multiple copies of the same packet and letting the receiver discard duplicate packets is often used to compensate for lost packets.

**Application Layer:** SA and short payload messaging were chosen as the applications running over this MANET. In addition to standard SA and short messaging applications, radio embedded short messaging and SA applications were also developed so that user of radio can send and receive SA messages and short payload messages without the need of external laptop/PDAs. External laptop/PDAs are only attached to selected nodes as needed to provide graphic network topology displays and to run standard SA and short messaging applications.

## IV.2 Field Test Results

Field tests were performed to evaluate the performance of SA and short payload messaging over MANET. Figure 7 shows a screen capture of MobileRoute Observer with location, network topology and node list information displayed.

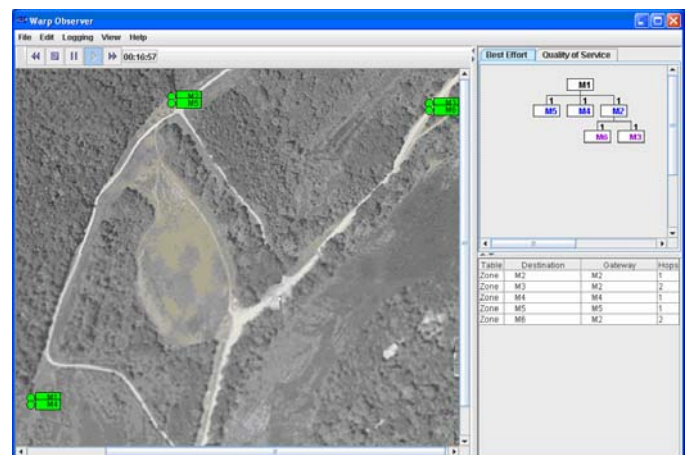


Figure 7 - MANET Network Topology

Test results showed that all team members' locations can be tracked smoothly by other team members while simultaneously performing messaging and chat over this MANET.

### IV.3 Potential Future Improvements

Several potential future improvements of this MANET implementation over legacy tactical radio waveform could be considered:

- The gateway capability could be implemented to connect multiple MANETs over different physical channels and to provide a reach back capability for SA and short messaging applications.
- The multicasting capability could be improved to provide more efficient many-to-many communications.
- MobileRoute's QoS routing capabilities could be enabled to provide enhanced routing based on energy efficiency or link stability.
- Further optimization of MAC layer performance is possible to increase the effective network throughput.
- Voice range extension through multi-hop voice network support could be added to provide important tactical operational benefits.

### V. CONCLUSION

Implementing a mobile ad hoc network over a legacy tactical radio waveform is feasible and effective. Situational Awareness and Short Payload Messaging are the ideal tactical networking applications for such a network. MANET over legacy tactical waveform can support voice/data interoperability with legacy tactical radios while providing advanced networking capabilities. Careful design can mitigate the impact of legacy tactical radio link characteristics. Radio embedded routing and networking applications can support MANET without the need of external data terminals. Due to the large number of fielded radios supporting legacy tactical waveforms and the limited spectrum availability in the VHF/UHF band, MANET over a legacy tactical radio waveform can provide the war fighter a much needed self-forming and self-healing ad hoc networking capability today and complement the wideband networking technology planned for future deployment.

### VI. ACKNOWLEDGEMENT

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