TARMAC: Traffic-Analysis Resilient MAC Protocol for Multi-Hop Wireless Networks

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Abstract—Traffic analysis in Multi-hop Wireless Networks can expose the structure of the network allowing attackers to focus their efforts on critical nodes. For example, jamming the only data sink in a sensor network can cripple the network. We propose a new communication protocol that is part of the MAC layer, but resides conceptually between the routing layer and MAC, that is resilient to traffic analysis. Each node broadcasts the data that it has to transmit according to a fixed transmission schedule that is independent of the traffic being generated, making the network immune to time correlation analysis. The transmission pattern is identical, with the exception of a possible time shift, at all nodes, removing spatial correlation of transmissions to network structure. Data for all neighbors resides in the same encrypted packet. Each neighbor then decides which subset of the data in a packet to forward onwards using a routing protocol whose details are orthogonal to the proposed scheme. We analyze the basic scheme, exploring the tradeoffs in terms of frequency of transmission and packet size. We also explore adaptive and time changing patterns and analyze their performance under a number of representative scenarios.

I. INTRODUCTION

Technological advances in VLSI, MEMS, and wireless communication have ushered in a new age of miniature, low cost, low-energy, micro-sensors. Networks of such devices, called Wireless Sensor Networks (WSNs), hold the promise of revolutionizing sensing across a range of civil, scientific, military and industrial applications. This emerging technology provides an opportunity to collect information at unprecedented resolution due to their low cost, small size, ease of deployment, and ability to provide fine-grained up-close sensing. It is anticipated that instrumenting physical environment with thousands of tiny sensing devices can significantly improve our understanding of the real world and provide one of the necessary interfaces between the physical and digital worlds.

Traffic analysis can be of major concern to secure multi-hop wireless networks. Since packets are transmitted over open air, they can be easily intercepted. The use of encryption protects the confidentiality of the data. However, the network becomes vulnerable to traffic analysis where an adversary can extract the pattern of communication if not its contents. Knowing the pattern of communication can be used to guide more effective attacks on the network. For example, the attacker can jam a base station or critical relay nodes to cripple large parts of the network with a modest effort. Further, the information about what nodes are communicating can itself be sensitive. For example, in a military scenario, if an adversary observes increased sensor activity in an area, it may deduce that its assets there have been discovered and move them before they are attacked.

The main enabler for traffic analysis is that data communication is event driven. Thus, when a node has data to send, it sends it immediately, subject to its MAC layer protocol. An attacker, can derive the presence of data from the time correlation of packet sends. Further, it can extract the spatial communication pattern by tracking which relay nodes forward a packet onwards.

Thus, to protect from traffic analysis, the data traffic must be engineered to make it impossible to extract temporal or spatial correlation of physical transmission to the presence of data. We discuss some of the existing related work in Section II.

The primary contribution of this paper is a Traffic-Analysis Resilient MAC protocol (TARMAC). In TARMAC the traffic generated by each node is independent of data (and control packets) to be sent by it. Instead each node sends encrypted frames, each consisting of multiple packets, in a pattern that is the same across all nodes, with the exception of a possible time shift that is independent of the data. The generated frame is broadcast locally without a specific destination and is received by all neighbors. The size of the frame is independent of the amount of actual data it contains (for example, it may be constant in size). Each frame consists of all the data the node has to transmit to all its neighbors (up to the size of the frame).

Neighboring nodes pick up the broadcast frame, and may decide to forward portions of it onwards when it
is their time to send according to the routing protocol (which is orthogonal to this functionality, but as we show later, could gain from being aware of the transmission pattern). Thus, each packet may contain multiple pieces of data destined to different locations. Each receiving node may forward a subset of the data packets in a frame, combined with other packets from other nodes, in the next frame it generates.

A useful analogy is a vehicle transportation system. Existing MAC protocols have data packets each using their own car (even-driven transmission), allowing an intruder to simply observe the presence of a car to detect data transmissions and to follow the car’s progression to extract spatial pattern of communication. In TARMAC, there are only buses that leave to preset locations at scheduled intervals. At every stop, passengers from different arriving buses may hop onto other buses that take them towards their destination. To an outside observer, the buses always leave on schedule, regardless of what passengers are inside them (or in fact, whether there are any passengers at all).

Different routing protocols and, in fact, link layer ones can inter-operate with TARMAC. The routing protocol defines how the data packets are processed at the next hop (how passengers move from bus to bus). For example, the source may indicate who the next hop is, say by geographic routing, and in that case, only the designated next hop forwards a piece of data. Any other routing protocol can be used instead. Similarly, Link level reliability may be implemented by having the next hop acknowledge a packet when it is its time to broadcast. Alternatively, as each node broadcasts packets the next hop forwarding a packet can act as an implicit acknowledgement. The scheme is described more formally in Section III.

Clearly, analysis resilience comes at a cost. For example, having to follow pre-set schedules implies that average packet delay will be higher; passengers that use public transportation expect a longer travel time than those with their own car. Further, to make the structure of the network resistant to analysis, the pattern of transmission should be independent of the location in the network; otherwise, the pattern is open for spatial analysis where critical nodes are identified by their level of activity. In contrast to traditional bus systems, where buses merge at intermediate hubs that have much higher activity than edge stops, for passenger exchange, this model requires over-provisioning such that even distant stops act as hubs. As a result, it is likely that many of the frames near these edge stops do not have many passengers (otherwise, hubs wont have enough buses to carry their passengers). We analyze these tradeoffs and explore the effect of critical parameters such as send rate, frame size and traffic pattern on the performance of the basic TARMAC.

We also consider approaches for improving the efficiency of the scheme in Section VI. More specifically, we explore adapting the transmission pattern (uniformly) to match the desired capacity. Further, we explore time-varying transmission schedules where only portions of the network display high transmission rates at a given time. The portions of high activity change over time such that all nodes still have the same transmission pattern (only shifted in time). The routing protocol is aware of the changing capacity and can direct packets to areas of the network that currently have high capacity. In Section VII we evaluate the basic scheme, as well as these improvements to it. Finally, Section VIII presents some concluding remarks.

II. BACKGROUND AND RELATED WORK

Deng et al [1] discuss the traffic analysis problem as it relates to Multi-Hop Wireless Networks (MHWNs). They isolate the following properties that enable traffic analysis: (1) Time correlation between receiving and forwarding a packet. Using this correlation an adversary can track the progression of a packet and extract the structure of the connections and network; (2) Unencrypted packets: if packets are plain text, they can be studied to find the next hop and this can be done successively to get to the base-station; and (3) Areas of interest and areas near the base-station generally have higher traffic, the activity level can then be used to identify such key points. Resilience to traffic analysis requires eliminating all three of the above ingredients.

Traffic analysis has been studied in the context of wired and wireless networks (e.g., [2], [3]). In wired networks onion routing [4] is the prominent anti-traffic analysis protocol. It camouflages the destination by routing through intermediate proxies. In wired networks, however, hop-to-hop behavior is not in question and only the source and destination are being protected. In wireless networks, the channel is broadcast in nature and there is a correlation between receiving a packet and sending it and this can be used to determining flow directions. Also, since wireless networks generally have low duty cycles a sudden increase in sending rates at a particular location would mean an event has taken place at that location.

Deng et al propose the use of multi-path multi-base-station routing to protect against traffic analysis [1]. Data packets flow up routing trees towards the base station. To prevent traffic analysis each node transmits
at fixed time intervals irrespective of the data present. If a node has data, it forwards it in its allotted time slot, otherwise it just forwards dummy packets. If a node does not hear its packet forwarded, it keeps sending the same packet when its time slot arrives. This scheme is different from TARMAC in a number of ways. TARMAC takes advantage of the broadcast nature of the wireless channel to group all outgoing packets from a node together. Deng’s approach attempts to reduce hot-spots by limiting flows feeding into a hot-spot. They do not protect control packets that need to be flooded in the network. The latency is much higher for this approach because a node transmits a packet to its parent only when it starts transmitting dummy packets or it over hears the parent node transmitting its packet. Every node has to change the encryption so that packets are not followed easily by an adversary. In TARMAC, the packets are disassembled and reassembled at each node; thus, it does not require that a unique key be applied at every hop.

In a followup work [5] the authors propose randomizing the path taken by every packet so that a pattern is not found. They also propose having some packets in addition to their path take random fake paths to take an adversary in the wrong direction. The paper goes on to propose generating random areas of high traffic (hot-spots) to misguide an adversary. This solution is a routing level solution with different properties than TARMAC. To our knowledge these are the only works on traffic analysis in sensor networks. We compare TARMAC against both of these works in Section V.

III. TARMAC: BASIC SCHEME

In this section, we present the basic TARMAC scheme. We also discuss tradeoffs and expected behavior of this base model. The drawbacks of the model in terms of energy efficiency and increased contention pave the way for the suggested improvements in the next Section.

A. Basic TARMAC Scheme

TARMAC is a MAC layer protocol that takes in to consideration the makes traffic resistant to analysis by using uniform (but possibly time-shifted) transmission schedules at all nodes. TARMAC emulates the communication network alternative of a city bus system. TARMAC uses encrypted frames that are sent at pre-scheduled times (it can inter operate with different link/MAC layers), irrespective of the presence of data packets. Different outgoing data packets, possibly targeted to different destinations and next hops, are placed in the same TARMAC frame; any empty slots are left empty. Note that empty slots are hidden by the encryption and the occupancy of each frame is not visible to the attacker. Each receiver of the frame can examine it and decide which packets are its responsibility to forward: virtually any routing protocol can be used to establish routing responsibilities.

TARMAC frames resemble public buses in that they have a fixed number of slots and leave at pre-scheduled times, with passengers (data-packets) taking up seats in the bus. In typical public transportation systems, provisioning is not uniform: for example, stops at remote routes have much lower bus activity and perhaps smaller buses than a central hub where many routes converge. Thus, extracting the structure of the public transportation network by simply observing the level of activity at a stop becomes possible.

To protect against such analysis TARMAC requires that all nodes follow the same schedule (later, we consider the possibility of a time-shift). The basic TARMAC scheme we discuss in this section is one where all the nodes transmit with a fixed period and fixed size packets; later we explore relaxing this model. Having the transmission times and sizes be uncorrelated to the data transport being carried through TARMAC makes it impossible to detect the presence of, for example, event based data. Furthermore, the broadcast nature of the wireless medium hides information about the receiver of the packet; thus, a TARMAC frame is like a number of concurrent buses that leave to each of the one-hop neighbors.

In contrast to these advantages of TARMAC, conventional MAC transmit data only when there is data to transmit, providing valuable information to attackers. Further, a data packet can be followed as it is retransmitted by intermediate hops to extract the full connection and the eventual destination.

B. Basic Parameters and Provisioning

In the basic model with periodic equal size frame, the relevant parameters are the transmission period $\tau$ and the size of the frame in slots $s$. The capacity, measured in slots per node per second, for the basic TARMAC can theoretically be expressed as $\frac{1}{\tau}$. Within the physical limitations of the channel, increasing either $s$ or reducing $\tau$ leads to increasing capacity by either sending larger packets or sending packets more often respectively. However, sending smaller frames more frequently fosters shorter delays, but increases frame overhead. In addition, larger size frames are more vulnerable to collisions and transmission losses.

A tension between the capacity of the network and the energy efficiency of TARMAC arises. At one extreme,
all nodes may be made to appear like a remote station, leading to energy efficiency but loss of capacity since the bottleneck nodes now do not have sufficient capacity to carry the offered load. On the other extreme, the network may be provisioned so that all nodes are transmitting at a sufficient rate to enable the bottleneck nodes to continue to forward the traffic. This leads to excessive overhead in remote or idle areas. These and other drawbacks are discussed in the next subsection.

C. Drawbacks of Basic TARMAC

To be able to carry the required traffic, the basic TARMAC must be provisioned sufficiently such that \( \tau \) is greater or equal the required traffic at bottleneck nodes. However, provisioning for the worst case has the following drawbacks:

- **Over or under-provisioning:** it is difficult to predict what the maximum bottleneck capacity is for some networks. The maximum reporting rate may be difficult to predict or the deployment may be ad hoc making a-priori analysis of bottleneck nodes difficult. As a result, the choice of \( s \) and \( \tau \) may lead to insufficient capacity to carry the reported data and leading to increased delay and loss of data as buffer sizes grow. Alternatively, it may lead to more aggressive sending and loss of efficiency as most slots remain idle.

- **Possible High Energy Cost:** By provisioning to the rate of the expected bottleneck, most of the nodes will be transmitting at a rate higher than that needed to carry their traffic. We note here that as long as an average occupancy of more than one slot per frame the total number of transmissions will be reduced. However, the size of each frame will be likely be bigger than the size of the individual data packets due to over-provisioning; some savings in framing and protocol overhead may result from combining multiple packets into a single transmission.

- **Low maximum throughput:** As the node capacity is increased by reducing the period or increasing the size, all nodes start sending more aggressively and the contention level increases. This includes nodes that do not have high occupancy, limiting the maximum throughput that can be achieved by nodes that do have data to send.

- **Increased delay:** Since each node is not forwarding the packets as soon as it gets it, there may be a larger packet delivery latency as packets wait for the next frame transmission at every intermediate hop.

In the next section, we identify a number of improvements to the base TARMAC that address some of these drawbacks.

IV. IMPROVEMENTS AND EXTENSIONS

In this section we discuss a number of improvements to the basic TARMAC in response to the drawbacks identified in the previous section.

A. Adaptive TARMAC

Static provisioning of TARMAC in terms of \( s \) and \( \tau \) can lead to a TARMAC configuration that is either insufficient to sustain the reported data, exceeds even the bottleneck requirements, or unsustainable in some areas of the network due to exceeding the capacity of the channel. We propose an adaptive version of TARMAC that allows adjustment of the reporting rate or bus size and works as follows.

- **Increasing capacity:** When a node detects that its traffic demands exceed its capacity, it requests an increase in the reporting rate. The increase is requested from the base-station (or a rate regulation leader), which can periodically adjust the overall rate based on the observed behavior. Adjustment is initiated through a flood packet (within the TARMAC mechanism) that proposes a new rate and a time when the nodes should switch to it. Precise synchronization is not needed. The nodes then all switch to the new rate.

- **Reducing capacity:** Capacity should be reduced in two cases: (1) a TARMAC rate exceeds local channel capacity; and (2) the TARMAC rate is too high and exceeds the need of all nodes. In the first case, nodes may elect to reduce capacity if the current TARMAC rate locally exceeds the available bandwidth. This will occur in high density areas. A reduction in schedule in such a condition is allowed because it does not reflect information about the traffic, but only the local density. In the second case, several options are possible, including tracking the maximum occupancy observed by packets along the way, and informing the regulator if the maximum of these is low.

Note that adapting the transmission activity to the bottleneck load allows attackers to detect the bottleneck level of activity of the network (but not where this bottleneck is). However, we believe that the advantages in terms of capacity and efficiency makes exposing this information worthwhile.
B. Use of Multi-Path Routing

High energy expenditure and low effective capacity may arise in basic TARMAC due to frames that are sparsely populated, wasting energy and occupying available channel time, leaving less of it available for frames carrying data. In response to this problem, we propose that the routing protocol should be aware of the TARMAC characteristics. For basic TARMAC, this entails the use of multi-path routing [6] to take advantage of the available capacity in nearby nodes. In conventional multi-hop wireless networks, the use of multi-path routing often does not lead to appreciable improvement in capacity because some of the links making up the different paths may be in interference range with each other, reducing the available bandwidth for each. For TARMAC, this is not the case because multi-path routing simply takes advantage of the available slots and does not require any additional transmissions.

C. Non-uniform TARMAC Schedule

Thusfar, we have assumed that the identical schedule maintained by all the nodes is a simple periodic one where all nodes transmit at the same period and with the same size. As we have seen, these leads to uncontrolled contention, especially in areas that are dense. However, an interesting possibility is to allow periodic schedules that do not have a fixed transmission rate. For example, nodes may alternative between a high send rate and a low send rate state. At a given instance, only some of the nodes are in the high rate portion of their schedule and contention is reduced. More complex schedules, as well as the possibility of adapting the schedule, are also possible. All nodes have the same schedule, with the exception of a time-shift, retaining the desirable traffic-analysis resilience features.

Within these general parameters a large solution space emerges based on the type of the schedule, and coordinating which nodes are in the high send rate together. These sets of nodes must be sufficient to provide connectivity and capacity to carry the desired traffic. Further, since the set of high rate nodes (which are most suitable as relay nodes) changes with time, the routing protocol should be able to adaptively use the high rate nodes.

A promising example of this class of TARMAC is one where nodes self-organize into clusters and synchronize activity periods such that at least one node is active at any given time. Routing based on zone addresses (e.g., as in GAF [7]) is then used to automatically use the current high rate node as the forwarding node for connections going through these area. As nodes change schedules they change forwarding responsibilities; nodes about to become forwarders should retain recent packets that have not been forwarded yet so that they can forward them when they switch to the high rate mode. We do not study this flavor of TARMAC in this paper. We intend to do so in a follow-up paper in the near future.

V. Experimental Evaluation

In this section, we present an experimental evaluation exploring the performance of TARMAC under different conditions, and compare it against two existing schemes for protection against traffic analysis in sensor networks[1], [5]; we call these solutions Intrusion 1 and Intrusion 2 respectively. We also compare against an unprotected network to evaluate the overhead necessary for camouflaging traffic. We implemented TARMAC in network simulator NS2 (version 2.29) [8], by extending IEEE 802.11 MAC protocol according to our design. To enable fair comparison, we also implemented Intrusion 1 and 2 on NS2 (they were implemented on TinyOS originally).

In our experiments, 100 sensors are regularly deployed in $10 \times 10$ grids covering an area of $200 \times 200 \text{meter}^2$, in which each node is located at the center of each grid. The table I shows some simulation parameters general for all studies. Other simulation parameters are summarized in Table II unless explicitly stated.

| Parameter          | value       |
|--------------------|-------------|
| No. of Data Sources| 100         |
| Traffic type       | CBR         |
| CBR packet size    | 32B         |
| Transmission Range | 40 meters   |
| BandWidth          | 2Mbps       |
| Routing Period     | 5 seconds   |
| Traffic Period     | 100 seconds |
| Simulation Period  | 400 seconds |
| TARMAC slot size   | 64 Byte     |

TABLE I

SOME SIMULATION PARAMETERS

A. Analysis of Basic TARMAC

Figure 1 shows the delivery ratio of shortest path routing on TARMAC as a function of the size of the frame and the transmission period. When TARMAC has a small period, even when the buses are small, the delivery ratio is high since the collision ratio is low as bigger frames suffer more collisions (Figure 3). When the period is large, if the bus size is small, then the effective capacity is not sufficient to carry the packets
leading to increased packet delay and reduced delivery ratio.

When the bus size increases, more collision happen and more packets are dropped due to collisions. For those with longer periods, the delivery ratio increases since each frame carries more packets. After some point, the collision ratio dominates as the physical capacity of the channel is reached. Figure 2 shows the occupation ratio of TARMAC bus packets (effective packets / number of slots). As can be expected, the longer the transmission period, the higher the bus occupation ratio. Figure 3 shows the average delay of all effective packets. As the transmission period increases, the time to get from source to destination increases. The smaller the buses are, the longer is the time needed to reach the destination as packets wait at each intermediate node. Figure 4 shows the energy consumption per packet. More energy is expended when the period is reduced (sending more often) or when the frame size is increased.

B. TARMAC with different traffic patterns

In this section, we study the performance of TARMAC under different traffic patterns. In the same grid scenario, we change the number of data sources and their distribution in the networks, considering the following 3 cases: all nodes as data sources, \( \frac{1}{3} (\sim 35) \) nodes as data sources and a quarter of nodes in the same corner are data sources. We also study two CBR send rates: 2 packets per second and 1 packet per second.

Figure 5 shows the delivery ratios of TARMAC with different traffic patterns. As can be expected, the higher the data rate, the lower the delivery ratio. The capacity of the bus also impacts the delivery ratio. The delivery ratio of pattern with 35 nodes is higher than that of only 25 nodes. The reason is that those 25 nodes are in the same crowded area creating hotpotting along the path to the basestation. The average delay and energy consumption are shown in figures 6 and 7 and follow expectations.
C. TARMAC vs Intrusion 1

In this study, we compare the performance of TARMAC and the Intrusion 1 solution [1]. We select one node as a data sink in the up-left corner of the simulation area. Each node in the network generates a CBR data traffic to the sink with a 2 packets per second rate.

Figure 5 shows the overall delay of TARMAC and Intrusion 1, against that of Shortest Path routing which serves as an upper bound on performance. As we can see, the buffer size affects the performance of intrusion 1 as well as bare SP. But TARMAC is not affected apparently by the buffer size. The reason may be due to the broadcast nature of TARMAC, and the unicast nature of intrusion 1 and SP. Since they use unicast, both intrusion 1 and SP may forward packet with best effort, holding packets for possible retransmission until success. TARMAC only holds packet for next available bus. So if the transmission period is low enough, the required buffer size is not big.

Figure 6 shows a somewhat surprising result about the energy consumption per data packet received by the data sink. The energy consumption per effective packet of TARMAC is nearly the same as the ideal optimal solution. However, this result is reasonable since each data packet is transmitted at each hop only once, requiring nothing more than itself (in term of transmission). Another reason leads to this result is the lower delivery ratio. Some packets were dropped at the early stage of its traveling from source to sink. We can reach this conclusion more directly from Figure 7 and 8. Since unicast transmission used by intrusion and SP requires control packets (RTS/CTS, ACK, etc.), the number of packets transmitted physically is higher than that with broadcasting: with TARMAC, all packets –routing, arp, data– are transmitted through broadcasting. \( M/m \) refers to the total number of packets transmitted physically (MAC layer packets) over the number of effective packets (data packets received by sink). \( S/m \) indicates the total size (in bytes) of packets transmitted physically over the size of effective packets.
Figure 9 shows the average end-to-end delay of all effective packets. The average delay of TARMAC is shorter than that of SP may due to the lower delivery ratio (most packets with longer delay are dropped before reaching the sink).

D. TARMAC vs Intrusion 2

Intrusion 2 [5] does not buffer incoming packets; only one packet is held for forwarding at each hop. Each node keeps sending the held packet until it overhears the forwarding of the corresponding packet at the next hop. Buffer size does not affect the performance of TARMAC as well as was shown in the previous section.

Figure 10 shows the delivery ratio of TARMAC and intrusion 2 with respect to the fixed transmission rate. The black straight line stands the delivery ratio of ideal optimal solution (SP). As the fixed transmission rate decreases, the delivery ratio decreases as well since the capacity of the bus decreases. As we can see if the buffer size is double of TARMAC, the performance is considerably better. Intrusion 2 can not benefit the increasing of the buffer size due to its design is just holding one packet. Figure 11 shows the energy consumption per effective packet. The situation is the same as we discussed before. Intrusion 2 tries to retransmit a data packet many times at each hop through the forwarding path. Meanwhile, no matter what the buffer size is, TARMAC just forwards each packet once at each hop.

Figure 12 shows the average end-to-end delay of all effective packets. The straight line at bottom is that of the ideal solution (SP). At first, the average delay of TARMAC with all buffer sizes are shorter than that of SP, perhaps due to the lower delivery ratio: most data packets with longer delay were dropped. As the buffer sizes increase, the average delay of TARMAC increases.

E. Evaluation of Multipath Routing and Adaption of TARMAC frame frequency

The routing layer is orthogonal to TARMAC, however, if it makes uses TARMAC it can greatly increase its...
performance. Let us assume that the routing layer just implements, say, shortest path routing. Now, if there is an event at a certain location and all the nodes at that location start sending data suddenly, the capacity of the network will be reached and the queues would fill up causing packets to be dropped. In addition to this, the empty TARMAC frames from nodes adjacent to the data flow would interfere with the data flow causing further drops. However, if the routing layer took advantage of the presence of TARMAC, it could employ multi-path routing. This would mean that the frames that were originally empty would now hold data packets and portions of the data would follow different paths to get to the destination. This would increase the delivery ratio, reduce the load on the network capacity and decrease the overhead as now the frames are carrying packets rather than being empty. The figure 10 shows the effects of multipath routing and the adoption of frame frequency. The adoption and multipath routing helps more packets passing through the network if density of data sources are high. The does not help to much (or even hurt) those with lower data sources density, since more collision may happen.

VI. CONCLUDING REMARKS

In this paper, we proposed a novel traffic-analysis resistant MAC protocol that replaces typical data-driven protocols with a fixed transmission schedule. TARMAC can interoperate with any routing protocol (although one that is aware of its characteristics can best utilize it). Further, while we evaluated TARMAC with a contention based MAC, it can interoperate with other link layer protocols, including TDMA based ones, or be extended to support reliability.

We evaluated the characteristics of this scheme, compared to existing approaches and showed that it offers significant performance advantages. Further, we discussed improvements to the basic TARMAC to further improve its efficiency without compromising its resilience to traffic analysis.
Fig. 17. Transmission Cost ($$/m$$)

Fig. 18. Average End-to-End Transmission Delay

Fig. 19. Multipath Routing and Adaption gain

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