A Survey of Vehicular-based Cooperative Traffic Information Systems

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***Abstract*— This paper summarises the research on cooperative traffic information systems based on vehicular ad hoc networks. Such systems are a promising concept for exchanging traffic information among vehicles. Their application enables reductions in fuel consumption, greenhouse gas emissions and travel time. Three classes of such systems are studied: infrastructureless solutions based on inter-vehicle communication, infrastructure-based solutions relying on the peer-to-peer paradigm and infrastructure-based systems using client-server architectures. Systems within each class are briefly introduced and their strengths and weaknesses are analysed.**

***Index Terms*— Cooperative traffic information systems; vehicular ad hoc networks; intelligent transportation systems.**

I. Introduction

The application of wireless technology to moving vehicles enables the creation of vehicular ad hoc networks (VANETs). Four main transmission types are present in VANETs [1]: *in-vehicle* – communication between electronic units within a vehicle, *vehicle-to-vehicle* (V2V) – communication among nearby vehicles, *vehicle-to-infrastructure* (V2I) – communication between vehicles and roadway infrastructure, and *vehicle-to-backoffice* (V2B) – communication between vehicles and a central entity via standards, such as GSM or UMTS. Three basic groups of applications are envisioned in VANETs [1]: (i) *safety-related*, (ii) *infotainment and advanced driver assistance services* and (iii) *resource efficiency (traffic, environment)*. This article deals with the last group. Efficient traffic management is becoming of great interest today as traffic congestion becomes a more and more severe problem. Vehicles that are idling, or travelling at reduced speeds due to congestion not only waste time of their users but also emit more greenhouse gas and utilise more fuel. Therefore, congested flow conditions have a negative impact on the economy, health, and environment. Moreover, information about traffic conditions along the route tops the list of consumer interests in transportation information [2]. In addition, traffic efficiency applications do not require such a high market penetration level of VANETs as is the case for safety-related applications.

The improvement of traffic flow and congestion reduction can be achieved by means of *traffic information systems* (TIS). In general, their aim is to capture, evaluate and disseminate traffic-related information. The solutions that are currently used rely on conventional equipment like traffic cameras, infrared sensors, ramp meters and traffic signals. The information is processed by a *traffic information agency* and then typically provided to the navigation systems of vehicles using the Traffic Message Channel (TMC) technology. The TMC messages are embedded into conventional FM radio broadcasts using the Radio Data System (RDS) communications protocol. However, there are four main drawbacks to such an approach. Firstly, it is completely centralised. Secondly, as it is based on a fixed and costly infrastructure, it is limited to the main roads (typically motorways). Thirdly, it lacks dynamicity, that is, information updates are far from real-time as delay is typically in the range of 20–50 minutes [3]. Lastly, the RDS technology offers very restricted bandwidth, therefore, traffic information has to be limited in details. These drawbacks can be overcome by *cooperative traffic information systems* (CTIS), where traffic-related information is collected individually by vehicles and exchanged between themselves using wireless networks. CTIS provide vehicles with real-time traffic information allowing dynamic route guidance. Location awareness is provided to system users by Global Positioning System (GPS) receivers. In general, CTIS can be classified as either *infrastructureless* or *infrastructure-based* [4]. The former are based on V2V communication. The latter use infrastructure-based communications technologies and might rely on centralised traffic information agencies.

The purpose of this paper is to review and describe basic principles of the CTIS proposed in the literature. To the best of our knowledge, this is the first attempt to survey past work done in this field. The paper is structured as follows. First, the main challenges of CTIS are presented. Next, in Section III, systems belonging to the infrastructureless class are presented. Their alternative, systems relying on infrastructure, is described in Sect. IV. The final section summarises and concludes the paper.

II. Cooperative traffic information systems

The infrastructureless CTIS typically apply *data aggregation* techniques to limit bandwidth use and maintain scalability. Usually, with increasing distance, observations regarding a given area become less precise. Thanks to *store-and-forward* techniques traffic information can be disseminated in multiple partitions of VANETs. For more information regarding communication patterns we suggest [5], [6]. As the information is a subject of interest to many vehicles in a given geographical area, the broadcast nature of V2V communication fits very well the objectives of infrastructureless CTIS. However, such systems have two main drawbacks in

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long distance information dissemination. Firstly, they have a relatively high delay and secondly the information is limited in its details (due to the distance-based data aggregation) [7], [8]. Another problem is that several overlapping aggregates for the same area may exist, making it difficult to compare them [4]. Therefore, the quality of V2V communication-based approaches greatly depends on the quality of the aggregation techniques. For more information regarding aggregation techniques for CTIS we suggest [9].

The drawback of infrastructure-based CTIS is that service charges will most probably apply. However, they can be deployed in the near future as in contrast to VANET technology, low-cost wireless Internet access will soon be very common [10]. Moreover, such systems require much lower market penetration compared to infrastructureless approaches. Infrastructure-based CTIS can rely on *client-server* or *peer-to-peer* (P2P) models of data storage and communication [11]. In the client-server approach, traffic information is stored in a server which is typically accessed by vehicles over the Internet. The question arises of how to deal with the huge number of updates and queries made to the system, therefore scalability is an issue [4]. In addition, in such systems a single authority decides who may access data [8]. However, compared to other solution types, client-server systems can provide much higher protection in terms of information security for its users [12]. Moreover, route computation can be performed by the server. Finally, the network layer problems that occur in V2V-based solutions can be avoided [10]. In order to obtain CTIS independent of central authorities and at the same time benefit from reliable infrastructure-based connectivity, a P2P architecture can be used in place of the client-server model. In such a case instead of using dedicated servers, data is distributed across the vehicles. The amount of traffic information is positively correlated with the number of participating vehicles, therefore P2P-based systems are scalable. However, when compared with client-server approaches, the P2P-based solutions use a greater overall bandwidth [10]. The key question in such systems is how to provide an information lookup service. A detailed comparison of P2P and V2V-based CTIS can be found in [4].

III. Infrastructureless approaches

A. SOTIS system

A Self-Organizing Traffic Information System (SOTIS) is proposed in [7]. It works within an approximate radius of 50 to 100 km of an individual user, even if as few as only 2% of all vehicles are using it. The precision of the information it provides decreases as the distance to the area of interest increases. The authors propose a distributed *receive-analyse-send* algorithm. The information received from other vehicles is first analysed, and only results of the analysis are transmitted. Roads are divided into variable size segments, and the information is exchanged on per segment basis. Each vehicle stores information for every segment of the road in its local database called *Knowledge Base* (KB). A GPS-based time-stamp is used to determine the accuracy of the information: more recent reports are assumed to be more accurate, and thus replace older ones. There are two types of reports generated by vehicles: *periodic* and *emergency*. The aim of periodic reports is to inform the surrounding vehicles about a vehicle's position, speed, heading and to provide its individual traffic analysis. These reports are generated periodically at time intervals based on the priority of the information. Upon reception of reports a vehicle updates its KB. The emergency reports are only used to send information about critical traffic incidents. Such reports have immediate access to the wireless channel. Each vehicle performs traffic analysis individually using its KB. An example of the analysis provided in the paper is the average speed of all vehicles in a given segment. Based on this information an estimation of road condition in a given segment is made. The reports are exchanged between vehicles travelling in both directions. The system was evaluated using the ns-2 network simulator [13] and a simple vehicular traffic simulator based on cellular automata.

In [3] the authors provide more information on the receive-analyse-send approach used in SOTIS. An adaptive broadcast technique is introduced: broadcast intervals are adapted according to *provocation* and *mollification events*. The former reduce the intervals, while the latter do the opposite. The paper provides an extensive set of both types of events. In addition, data aggregation is introduced, as vehicles calculate the average speed per segment.

B. TrafficView system

A system called *TrafficView* is presented in [14]. Its main objective is to gather and disseminate information about the position and speed of vehicles. The information is restricted only to the vehicles positioned ahead of the current vehicle. The approach for message exchange is very similar to that used in SOTIS: vehicles periodically broadcast reports (contained in a single packet) about themselves and other vehicles they know about. Whenever a vehicle receives a report, it updates its stored information, and sends the updated report in the next broadcast period. Although the average size of the stored records is very small (on the order of 50 bytes) data aggregation is performed in order to fit all information in a single packet. The authors propose aggregating data based on its semantics. For instance, the information about two vehicles that are close to each other and are moving with similar speeds will be stored in a single record. In consequence, the record represents information about a set of vehicles. The selection of data for aggregation is based only on the relative distances of the vehicles concerned. According to the authors, data compression techniques could further minimise the size of the records. However, due to the limited computation resources of portable devices, such techniques are not applied in this proposal. Collected data is processed into validated data sets using a *validation module*. The validation procedure resolves conflicts between the data records (e.g. multiple records containing information about the same vehicle), removes records containing information about vehicles behind its own vehicle, and updates estimated position of vehicles using the stored speed. Three different algorithms for selection of data for aggregation are introduced: *ratio-based*, *cost-based* and *information aging*. The aggregation procedure on the records in the validated dataset is performed before each broadcast period. Performance evaluation of TrafficView was carried out using the ns-2 network simulator and the CORSIM vehicular traffic simulator [15]. The authors developed their own vehicular traffic scenario generator. In [16] the authors show that the most efficient data dissemination in TrafficView can be achieved if messages are relayed only by vehicles travelling in the opposite direction.

C. TrafficRep system

In [17] the authors examine the efficiency of a V2V-based traffic information dissemination architecture. A small fraction of the vehicles is assumed to use a device called *TrafficRep* whose goal is to collect and disseminate traffic information. The device is connected to a digital map database, a GPS receiver and a wireless communications device. Roads are divided into segments. *A priori* travel time on a segment is set to the free-flow travel time. Each time a vehicle reaches the end of a segment, its TrafficRep device produces a *travel log report* (TLR). The report includes travel time corresponding to the segment, the identifier of the segment, and a time-stamp. Using V2V communication, vehicles periodically exchange TLRs. The authors evaluate two dissemination approaches, *naive scheme* and *smart scheme*. In the naive scheme, vehicles broadcast TLRs corresponding to recently travelled segments at a pre-defined rate of dissemination. Only TLRs for which the difference between the experienced and the expected travel time was greatest are transmitted. On the other hand, in the smart scheme, TLRs are sent when vehicles have significant information to share. As in the naive scheme, reports are also broadcast at a pre-defined rate of dissemination. These broadcasts are however limited to TLRs for which the difference between the experienced and the expected travel time was greater than a certain threshold. The proposed approach was evaluated using a calibrated traffic simulation model of the Southern New Jersey transportation network and the Paramics network simulator [18]. It is shown that market penetration between 3 and 10% is enough to obtain the full benefits of V2V communications technology for CTIS. Finally, the authors claim that if simple dissemination techniques like the smart scheme are used, then bandwidth is not an issue for VANET-based CTIS (contrary to the claim made in [14]).

D. StreetSmart Traffic system

The *StreetSmart Traffic* system introduced in [19] proposes to aggregate traffic information using distributed clustering algorithms with an epidemic diffusion model. It is designed to perform well even if only a small fraction of vehicles participates in the system. Moreover, the system does not require constant connectivity. Each vehicle records its speed and on this basis builds a local traffic map. Vehicles that are close to each other exchange their speed maps. However, the exchange is limited only to the maps with unusual speeds. In consequence, each vehicle is able to build a map of expected speeds on roads that other vehicles have travelled on. Data aggregation is performed using clustering techniques, which combine related recordings of an unusual speed. Cluster analysis is based on a modified k-means method. The authors suggest that unusual speed should not only refer to the posted speed limit but should also consider predictable trends. For instance, significant congestion on commuter routes at certain hours can be treated as an expected event, which does not require reporting. The system was evaluated using the authors own simulator of Manhattan's grid of highways and a random way point mobility model. The authors demonstrate, that extending the system with wireless base stations could significantly improve the performance of the system.

E. IFTIS system

In [20] the authors claim that the previous systems proposed in the literature (SOTIS and TrafficView) are not well adapted to city environments. Therefore, in [20] they introduce a new system called *Infrastructure-Free Traffic Information System* (IFTIS) to tackle the urban environment. Its main objective is to provide vehicles with an estimation of traffic density in city roads on a segment-to-segment basis. Based on the motivation that vehicles in geographical proximity often share similar traffic information, the authors introduce a location-based group concept, in which only a *group leader* is responsible for information broadcast. The main goal of the leader-based approach is to avoid scalability issues. A segment of a street between two intersections is divided into fixed size cells. Each cell has its centre. The knowledge about cell's location is *a priori* known by the vehicles. This enables them to be arranged into dynamic location-based groups defined by the position of the cells. The vehicle that is closest to cell centre is considered to be the group leader. Vehicles record information about the speed and direction of neighbouring vehicles. This allows them to estimate the traffic density (defined as the number of vehicles) of all cells in a segment in order to create a *Cells Density Packet* (CDP). As soon as a group leader reaches the intersection, it sends its CDP backwards to the beginning of the street section. Before reaching the beginning of the section, the CDP is updated by other group leaders that relay the packet. When its final destination is reached, it is propagated to vehicles around the intersection. The IFTIS system was evaluated using the Qualnet network simulator [21]. Mobility patterns were generated using VanetMobiSim [22].

F. Trafficinfo system

The *Trafficinfo* system introduced in [23] deals with bandwidth issues by using rank-based store-and-forward techniques. Similarly to the approach presented in [17], roads are divided into segments with unique identifiers. As soon as a vehicle reaches the end of a road segment it generates a travel time report for that segment (similar to that proposed in the TrafficRep system). Each vehicle broadcasts to its neighbours only the most relevant (highest rank) reports from its database. The rank of the reports is based on their supply and demand characteristics individually evaluated by each vehicle. Supply indicates the number of vehicles that already have the report. Each vehicle can estimate the supply of report R by analysing the number of times that R has been received from other vehicles (using a machine learning-based algorithm). On the other hand, demand of R depends on two spatial-temporal factors of the vehicle performing the evaluation: its distance to the road segment reported by R and age of the report. Broadcasts are triggered by the following events: (i) the vehicle receives a new travel time report from another system user, (ii) the vehicle reaches the end of a road segment and produces a new travel time report and (iii) the time since the last broadcast made by the vehicle exceeds a *broadcast time threshold* (BTT). The authors propose two ways of setting the value of BTT: static and dynamic. The former is a fixed threshold, while the latter is based on vehicle's speed and transmission range. Dynamic BTT guarantees that two vehicles travelling on the same road segment but in the opposite directions will initiate broadcasts at least once. The system was evaluated using the STRAW system [24], which integrates vehicular traffic and network simulators. A scenario corresponding to downtown Chicago was used.

IV. Infrastructure-based approaches

A. SOCRATES system

One of the first client-server CTIS was *SOCRATES* (System Of Cellular RAdio for Traffic Efficiency and Safety) introduced in [25]. However, only a generic architecture for the system can be found in this work. It assumes two-way cellular-based communication between vehicles and a *traffic information centre* (TIC) using 1/2G cellular technologies (Mobitex and GSM). The vehicles periodically send anonymous traffic reports (containing their position, status and travel time) to the TIC. The reports are stored and processed by the centre. On the basis on these reports the TIC calculates current conditions and also predicts traffic flows. The information is sent back to the vehicles. The authors claim that only between 1 and 2% of vehicles need to be equipped with the system in order to allow the TIC to calculate accurate traffic flows. However, no evaluation of the system is presented.

B. CoCar system

A client-server system called *CoCar* is proposed in [12]. The system is used to investigate the application of UMTS technology to CTIS. As in the SOCRATES system, the heart of CoCar is a TIC. Vehicles equipped with the CoCar system send traffic reports to the centre using Internet access via UMTS. The reports are aggregated and integrated with information obtained from other sources. The centre sends processed traffic information to all vehicles that belong to the cell from which the reports were originated. Communication between the TIC and vehicles is made using Fast Traffic Alert Protocol (FTAP). In order to limit the number of reports sent to the centre, a vehicle reports an incident to the TIC only if it has not received a similar report within a certain period. The CoCar system was evaluated using the OMNeT++ network traffic simulator [26] coupled with the SUMO road traffic simulator. A large motorway interchange in the Frankfurt area was used as a test case. The authors also analyse the environmental impact of the CoCar system using the model proposed in [27].

C. TraffCon system

The aim of the *TraffCon* system presented in [28] is to provide vehicles with driving directions (instead of keeping drivers better informed about traffic conditions as is the case for other systems). Its goal is to globally optimise the usage of the road network and avoid *flash crowd* driving patterns. A vehicle submits (using a cellular network) the information about its current position and desired destination to a TIC. Route computation is performed by the TIC, which calculates the quality of k shortest routes. The quality is defined by a fitness function. The vehicle receives the route with the best fitness value. The procedure is repeated periodically. Therefore, if traffic conditions change, or the vehicle does not obey the instructions, a new route is produced by the TIC. The quality of a route takes into account four objectives: travel time, effect on congestion, fuel consumption and gas emissions. As there is no other exchange of traffic information in the system, its performance strongly depends on the penetration rate of participating vehicles. TraffCon was evaluated using the SWANS ad hoc network simulator [29]. A small part of Boston (MA, USA) road network was used as the test scenario.

D. PeerTIS system

The idea of establishing a P2P overlay over the Internet for CTIS was first presented in [30]. Its aim is to reduce the information propagation delays present with store-and-forward techniques and at the same time to avoid typical drawbacks of a client-server approach. A full-fledged system called *PeerTIS* is introduced in [8]. Direct V2V communication between vehicles is replaced with a cellular network: using the IP-based communication channel vehicles create a P2P overlay over the Internet. Traffic information storage, lookup and exchange are based on the structured P2P paradigm. Subsequently, the observed traffic conditions are deterministically published to a particular node, based on the lookup mechanism. Roads are divided into segments with unique identifiers. Vehicles generate travel time reports similar to that proposed in the TrafficRep system. The reports are distributed and stored by the vehicles, while the lookups are performed using *distributed hash tables* (DHTs). Each entry of a DHT is a tuple *(key, traffic information)*. The key identifies the road segment. In contrast to most P2P applications, the usage pattern in the CTIS context has locality correlations: vehicles typically request or modify the reports about segments that are geographically close together. In order to keep these correlations the authors propose to remove hashing of the key from DHTs. This enables the topology of the geographical area to be maintained within the overlay network. Each key is specified by geographical coordinates of a road segment. The key space is divided into zones (one zone might contain several keys), which are then assigned to vehicles. Each vehicle stores the information assigned to all keys that belong to its zone. In addition, it is responsible for monitoring the situation concerning the zone. Participants in the system send their traffic reports to the vehicles responsible for the location covered by the report. When a new vehicle joins, it takes over half of the zone of one of the system participants. When the vehicle leaves, its zone is merged with other zones. The system was evaluated using the VISSIM road traffic simulator [31].

PeerTIS is further improved in [11]. The street network is represented by a graph, which is partitioned into subgraphs when a new vehicle joins the system. The handling of the updates is more efficient due to the introduction of a *publish/subscribe* scheme. Vehicles are informed about relevant changes regarding the segments they are subscribed to. The improved PeerTIS was evaluated using the SUMO road traffic simulator [32] coupled with the OverSim P2P simulator [33]. A realistic map of Düsseldorf was taken from the OpenStreetMap project [34].

E. Hybrid system

The idea of using a P2P overlay over an infrastructure-based wireless connection is also exploited in [35]. However, there are two main differences between the system proposed in this work (hereafter referred to as a *Hybrid system*) and PeerTIS. Firstly, in addition to a P2P overlay, it is also based on V2V communication. Therefore, a two-tier architecture is applied: in the lower tier vehicles communicate using direct V2V links, while in the upper tier a P2P overlay network is created. Secondly, unstructured P2P is used (PeerTIS has structured P2P). This means that system users have no knowledge about the mapping between traffic reports and the node that stores them. Vehicles that are close to each other are grouped into clusters using the Max-Min heuristic. The heuristic is also applied to select cluster heads. The vehicles selected as cluster heads are called *supernodes*, while the remaining system users are referred to as *regular nodes*. Due to the mobility of nodes the selection of supernodes is performed periodically. Members of a cluster exchange traffic information (defined as driving speed) using V2V communication. The supernode aggregates the reports into a single value. A two-step procedure is used. Firstly, the average driving speed in the cluster is calculated. Secondly, this average speed is mapped to one of the four *traffic Level of Service* (LOS) classes. For instance, if the average recorded speed on the highway is between 0 and 40 km/h, then it is mapped to value D. When a supernode needs traffic information about other clusters, it will contact other cluster heads using scoped flooding. A regular node requests traffic information by contacting the supernode of its cluster (using V2V communication). In order to limit the overhead of the lookup procedure carried out by supernodes, the authors propose adapting a location-based routing protocol. The system was evaluated using the SUMO road traffic simulator.

V. Discussion and conclusion

The future TIS will rely on the cooperation of vehicles, their drivers, infrastructure and traffic information agencies. Recently, several approaches introducing cooperative data collection and dissemination by vehicles have been proposed. The primary differences between them lie in the underlying communications technologies. A comparison of CTIS is given in Table I. The main issue of the infrastructureless systems – how to provide a scalable solution – is answered in several ways: by aggregating traffic information (SOTIS, TrafficView, StreetSmart), by sharing only the highest rank reports (Trafficinfo) or by limiting communication to selected nodes (IFTIS). These systems cannot be deployed in the near future, as one has to wait until the necessary market penetration of V2V communications technologies has been reached. However, the infrastructureless systems do not require such a high penetration rate of these technologies as one might expect: the authors of TrafficRep demonstrate that a market penetration between 3 and 10% is enough to obtain the full benefits of V2V communication for CTIS. On the other hand, due to the availability of low-cost cellular Internet, the infrastructure-based CTIS can be deployed in the near future. A client-server architecture allows such systems to globally optimise traffic flows (e.g. TraffCon), and include information from non-vehicular sources (e.g. CoCar). As infrastructure-based CTIS typically imply a centralised authority running the system, they have higher potential interest from commercial service providers and traffic authorities. However, they introduce a single point of failure. This problem is avoided if a P2P-based approach is used instead, that is, vehicles form a self-organising overlay network hosted by the Internet Protocol. However, the question that arises in such a case is on how to efficiently perform information lookups. For instance, in PeerTIS this is addressed by using DHT without hashing. The Hybrid system proposes another approach by combining unstructured P2P and clustering techniques (leaving the lookup duty to the clusterheads).

In order to identify the areas of interest, a common solution is to use fixed road segmentation known *a priori* to system users (SOTIS, TrafficRep, IFTIS, Trafficinfo, PeerTis). The significant question that each system should address is when to send the reports. In SOTIS the broadcast intervals are adapted according to predefined provocation and mollification events. Participants in TrafficRep send reports when reaching the end of a road segment only if they have significant reports to share. In StreetSmart only group leaders send the reports. The systems also differ in the type of information that is exchanged. It is typically average speed (SOTIS, TrafficView, StreetSmart), travel time per segment (TrafficRep, PeerTis) or traffic density per segment (IFTIS). On the other hand, in the TraffCon system there is no exchange of traffic information between vehicles. System participants submit their destinations to a centralised server, which returns driving directions. Therefore, cooperation between vehicles is achieved indirectly, using a centralised entity.

TABLE I

A COMPARISON OF INFRASTRUCTURELESS (V2V COMMUNICATION-BASED) AND INFRASTRUCTURE-BASED CTIS: COMMUNICATION SCHEMES, SCALABILITY TECHNIQUES, TYPES OF EXCHANGED EVENTS AND SIMULATION TOOLS USED TO EVALUATE THE SYSTEM.

		communication schemes	scalability	event types	simulation tools
V2V-based	**SOTIS**	V2V	information aggregation	avr. speed, warnings	ns-2
	TrafficView	V2V	information aggregation	average speed	ns-2, CORSIM
	TrafficRep	V2V	only significant information is exchanged	travel time	Paramics
	StreetSmart	V2V	information aggregation, only unusual information is exchanged	average speed	self-developped
	IFTIS	V2V	broadcasts only by group leaders	traffic density	Qualnet, VanetMobiSim
	Trafficinfo	V2V	exchange limited to top-rank reports	travel time	STRAW
infrastructure	**SOCRATES**	V2B	-	travel time	-
	CoCar	V2B	information aggregation	warning messages	OMNeT++, SUMO
	TraffCon	V2B	-	destination, directions	SWANS
	PeerTIS	P2P via Internet	P2P paradigm	travel time	SUMO, OverSim
	Hybrid	P2P via Internet, V2V	P2P, lookups by supernodes, information aggregation	average speed class	SUMO

The choice between infrastructure-based and infrastructureless solutions, as outlined in Section II, is multi-objective in its nature. It particular, it depends on the penetration ratio of a given communications technology, the level of security desired, and involvement of traffic authorities.

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