

Heterogeneous networks – increasing cellular capacity

Heterogeneous networks are an attractive means of expanding mobile network capacity. A heterogeneous network is typically composed of multiple radio access technologies, architectures, transmission solutions, and base stations of varying transmission power.

✦ SARA LANDSTRÖM, ANDERS FURUSKÅR, KLAS JOHANSSON, LAETITIA FALCONETTI AND FREDRIC KRONESTEDT

Enhancing and densifying the HSPA/LTE multi-standard macro-cellular network are additional methods of meeting increasing traffic demands and fulfilling users' high expectations for mobile broadband services. This article analyzes expansion strategies, covers important design choices for heterogeneous networks – focussing on transmission power differences – and explores how to coordinate low power nodes and macro base stations.

Introduction

Mobile broadband traffic has surpassed voice and is continuing to grow rapidly. This trend is set to continue, with global traffic figures expected to double annually over the next five years.¹ By 2014, the average subscriber will consume about 1GB of data per month compared with today's average figures that are around some hundred MB per month. This traffic growth, driven by new services and terminal capabilities,

is paralleled by user expectations for data rates similar to those of fixed broadband. Actual figures per subscriber can vary greatly depending on geographical market, terminal type and subscription type; some users with mobile devices are already creating traffic in the order of gigabytes and predictions are estimated to be several GB per month for some devices and certain user behavior. The mobile industry is, therefore, preparing for data rates in the order of tens of Mbps for indoor use as well as outside and gigabyte traffic volumes.

Improving, densifying and complementing the macro network

There are several approaches that can be taken to meet traffic and data rate demands (see **Figure 1**.) On a high level, the key options to expand network capacity include:

- ✦ improving the macro layer;
- ✦ densifying the macro layer; and
- ✦ complementing the macro layer with low power nodes, thereby creating a heterogeneous network.

These approaches are discussed here in more detail and use the example of a

dense urban environment to illustrate achievable performance. **Box B** details the reference system parameters..

Upgrading the radio access (HSPA or LTE) of existing sites enables very high user data rates and improved system capacity², which can be further enhanced through the addition of more spectrum, more antennas, and advanced processing within and between nodes. Increasing capacity and data rates in this way is attractive as it alleviates the need for new sites. **Figure 2** illustrates a reference system and the effect of each improvement approach on data volumes.

The reference system is a 10MHz HSPA system with an inter-site distance of 425m, achieving monthly data volumes per subscriber of 5.9GB in DL and 0.7GB in UL. By doubling the spectrum to 20MHz, data volumes for the DL approximately double. Figure 2 shows data rates achievable at low load with 95 percent coverage probability. In the DL, data rates of tens of Mbps are achieved. In the UL, however, this data rate is significantly lower (a few 100kbps) and increasing spectrum does not improve the situation. This condition is referred to as power limitation: data rates are limited by relatively low received power, which is due to large attenuation between terminal and base station caused by a combination of distance and challenging radio propagation (such as in indoor locations at the cell edge).

At some point, the capacity and/or data rates offered by the existing network with enhanced radio access will no longer be sufficient. If possible, densifying the macro network is an attractive evolution path in these cases. In dense urban areas, networks exist with

BOX A Terms and abbreviations

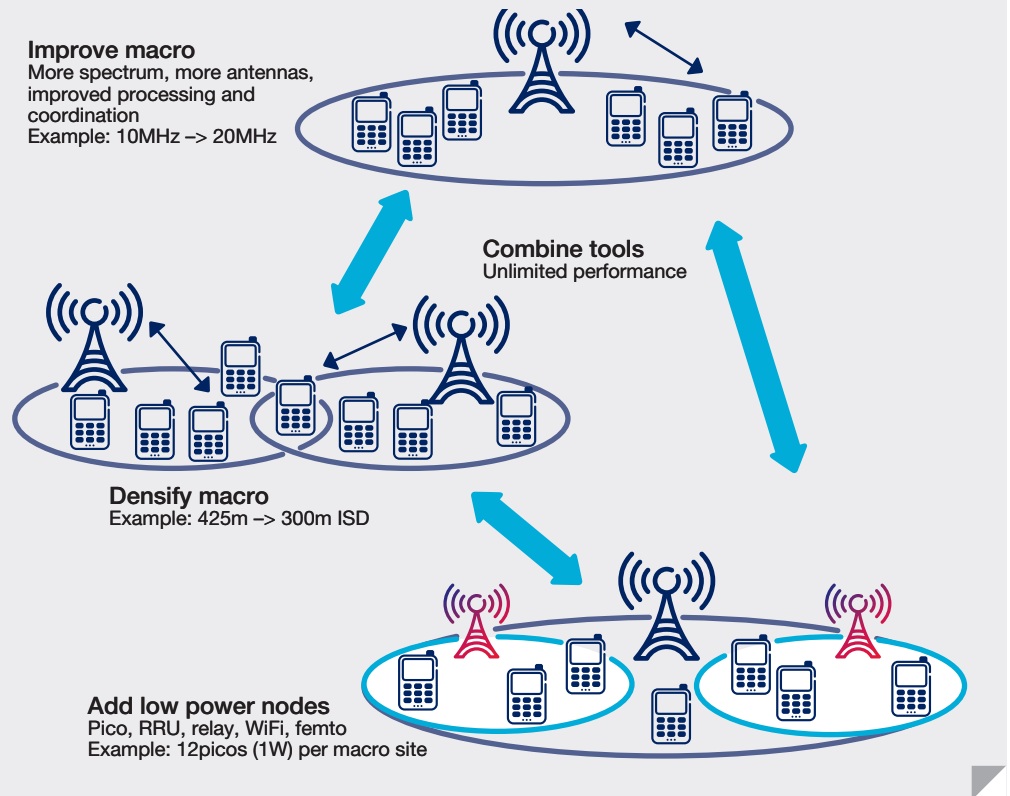
3GPP	3rd Generation Partnership Project	ICIC	Inter-Cell Interference Coordination
CDMA	Code Division Multiple Access	ISD	Inter-Site Distance
CSG	Closed Subscriber Group	LPN	low power node
DL	downlink	LTE	Long Term Evolution
dBm	power ratio of the measured power in decibels referenced to one milliwatt	RNC	Radio Network Controller
GSM	Global System for Mobile Communications	RRU	Remote Radio Unit
HARQ	Hybrid Automatic Repeat request	UE	User Equipment
HeNB	Home evolved Node B	UL	uplink
HSPA	High-Speed Packet Access	WCDMA	Wideband Code Division Multiple Access
		WiFi	Wireless Fidelity

inter-site distances down to 100-200m. Benefits of densification include: the number of sites is kept relatively low, and network performance is insensitive to traffic location. Figure 2 shows that by doubling the number of macro sites, DL capacity is doubled. The DL capacity per site remains more or less the same, since there are twice as many sites. UL capacity is more than doubled as users become less power limited – better capacity per site, twice as many sites. A significant increase in UL data rates is therefore achieved.

Complementing the macro networks with low power nodes, such as micro and pico base stations, has been considered a way to increase capacity for both GSM and CDMA systems for some time now (see references³⁻⁴). This approach offers very high capacity and data rates in areas covered by the low power nodes. Performance for users in the macro network improves if low power nodes can serve a significant number of hotspots and coverage holes. Deploying low power nodes can be challenging, as performance depends on close proximity to where traffic is generated. In addition, due to the reduced range of low power nodes, more of them are required. Overcoming these challenges requires proper design and integration of the low power nodes. Figure 2 shows results for the deployment of 12 pico base stations per macro site in traffic hotspots. This yields the same DL capacity increase as the previous two approaches (more spectrum and densification). However, a larger gain is achieved in the UL, which is a result of mitigating the power limitation. The resulting UL data rate improvement is greater than for the other two approaches.

The way to meet future capacity demand is by combining all three approaches: improving the macro layer; densifying the macro layer; and adding pico nodes, as indicated by the last example in Figure 2. How these approaches are combined and in what order depends on the existing network, targeted volumes and data rates, as well as the technical and economical feasibility of each approach. Such a heterogeneous network configuration, exploiting macro and low power nodes, can in principle support arbitrary data volumes and very high data rates.

FIGURE 1 Toolbox for higher capacities and data rates



Design options for heterogeneous networks

Several aspects govern effective design of heterogeneous networks. From a demand perspective, traffic volumes, traffic location and target data rates are important. From a supply perspective the important aspects include radio environment, macro-cellular coverage, site availability, backhaul transmission, spectrum and integration with the existing macro network. Commercial aspects, such as technology competition, business models, and marketing and pricing strategies must also be considered. To summarize, **Table 1** includes guidelines for some of the key design choices operators encounter.

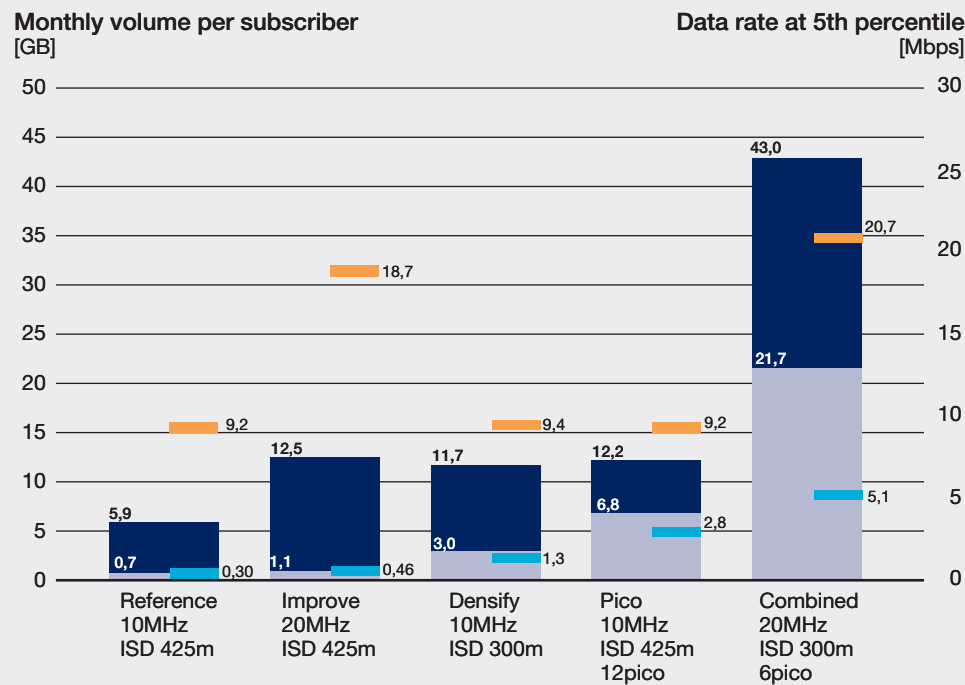
Deployment aspects and choice of radio-access technology

How to best complement the macro network depends on the network scenario. HSPA or LTE operating within the licensed spectrum should be used if the base station is deployed in a public area, or if coverage is important. If the

base station is well isolated from interference and range is not crucial – if it is used in a private home, for example – then WiFi exploiting unlicensed or license-exempt bands is an attractive solution. For authentication, simple sign-on, and access to mobile operator services the WiFi access point should be connected to the mobile core network. A 3GPP-based HeNB provides little gain over WiFi in such scenarios. On the contrary, HeNBs may create coverage holes or use spectrum that would otherwise be available for the macro layer.

In the network-design process, it is important to consider the business model. While a single operator often manages outdoor macro-cellular networks in urban areas, indoor systems are often shared between operators (cf Distributed Antenna Systems). WiFi access points and similar smaller scale solutions are often user-deployed (by individuals, enterprises or a third party), where access can be open for all subscribers or available for certain users only (Closed Subscriber Group ❖❖

FIGURE 2 DL and UL monthly data volumes and data rates at 5th percentile (95 percent coverage) supported by the different expansion strategies



❖ [CSG]). For public systems, particularly outdoors and in difficult radio environments, open access for all subscribers is important so that users connect to the best base station. This explains the first rule of thumb in **Table 1**.

Local traffic hotspots can cover a wide area, such as an entire block and include several buildings. In such cases, deploying an outdoor low power node that also covers indoor locations would be suitable. If the existing macro-cellular grid is too sparse to meet the traffic demand and provide adequate indoor service, deploying outdoor low power nodes is a useful technique to achieve general coverage improvement. When traffic is concentrated to one specific indoor location, such as a shopping mall, indoor deployment is preferable.

Type of low power node and backhaul solution

Backhaul transmission becomes more important as the number of nodes increase, in part because it will constitute a larger share of the total cost of

ownership, but also as the availability of fixed backhaul affects the feasible placements, installation costs, and time needed for site acquisition and installation. A low power node can be connected just to the core network or to the core network and other base stations. Each connection, also called backhaul link, may have different bandwidth and latency characteristics. The capacity of the backhaul link not only affects user throughput, but also the overall radio access network performance as a high-capacity backhaul allows for tighter coordination between nodes.

There are several types of low power nodes that put different requirements on backhaul support. For networks where the backhaul has low-latency and high-capacity characteristics, deploying remote radio units (RRUs) is the preferred approach; otherwise stand-alone pico base stations is an option.

An RRU has the potential to improve overall network performance through tight coordination between nodes and usually comprises antennas to send/

receive the radio transmission as well as a radio frequency processing unit. A central control unit that can collect baseband signals from several RRUs performs baseband signal processing and higher layer processing. The control unit and its distributed antennas/RRUs must be directly connected via a low-latency and high-capacity interface. An optical fiber-based backhaul is suitable for RRU deployment and such solutions are increasingly being used in HSPA high-capacity networks.

Where RRUs are not applicable, a stand-alone base station can instead be connected to the radio network controller (RNC) for HSPA and the core network for LTE. In contrast to RRUs, stand-alone pico base stations have loose backhaul requirements and may, therefore, fit with networks that have a high-latency and low-capacity interface. Two examples of cooperation schemes that can be applied to stand-alone picos are: soft handover in WCDMA Rel-99; and Inter-Cell Interference Coordination (ICIC) available in LTE release 8, which enabled simple interference management between base stations (picos and macros).

Additionally, a relay or repeater may be employed to improve coverage. The relay needs to communicate with the macro-cellular donor base stations, either inband or outband. If spectrum is available out-of-band relaying – using one band for the access link between terminal and relay and a separate band for the backhaul link between relay and donor base station – is the preferred approach.

Coexistence of macro and low power nodes

One of the basic issues with heterogeneous networks is how to determine the spectrum to employ in each cell layer, and for each technology – HSPA and LTE. To attain the highest possible data rates, it is necessary to use at least as much bandwidth as the UE is capable of handling in each layer. UE capability in terms of frequency bands influences spectrum possibilities: if capacity (high traffic volume) is the driver or spectrum is scarce, then macro-cellular carrier frequencies should be reused. However, such an approach requires good cell planning and radio resource

FIGURE 2. KEY

Performance evaluations

Blue bars
DL monthly data volumes

Light blue bars
UL monthly data volumes

Blue markers
UL 5th percentile data rates

Orange markers
DL 5th percentile data rates

management schemes to control interference between cell layers. In particular, mobility and control plane quality might be affected.

Our focus is on networks where macro-cellular carrier frequencies are reused throughout the network. By definition, a low power node has significantly lower transmission power than its surrounding macro base stations. Cell selection is typically based on DL received power, including the effects of the different base station transmission powers. This leads to an area surrounding the low power node where the macro base station is selected, but where the pathloss is lower towards the low power node. In the UL direction, where the transmit power is the same, it would be better to be connected to the low power node also in this area. This is illustrated in **Figure 3**. By increasing transmission power, the cell size of low power nodes can be increased. However, doing so affects the cost and size of the node, which in turn limits site availability.

The range of the low power node can also be increased using a cell selection offset or handover thresholds that favor the selection of the low power node. This leads to the UL being received in the best node (the low power node) and offloads the macro to a greater extent. These benefits, however, come at the cost of higher DL interference for users on the edge of the low power node cell. Without further coordination of macro and low power nodes, there is a trade-off between DL and UL performance. In HSPA, soft handover functionality is useful to increase the UL low power node coverage and capacity.

Coordination potential

In the situation just described signal strength is imbalanced. A highly promising solution for improving performance in this case is based on cooperation between the macro and the low power nodes within its coverage area. For LTE DL, cooperation supports efficient offloading by extending the range of the low power cell. For UL, cooperation enables the macro base station to exploit UE signals received at pico base stations. This is favorable due to the power-based cell selection (none or small cell selection offset) which creates a situation where pico base stations are often

BOX B

Performance evaluations

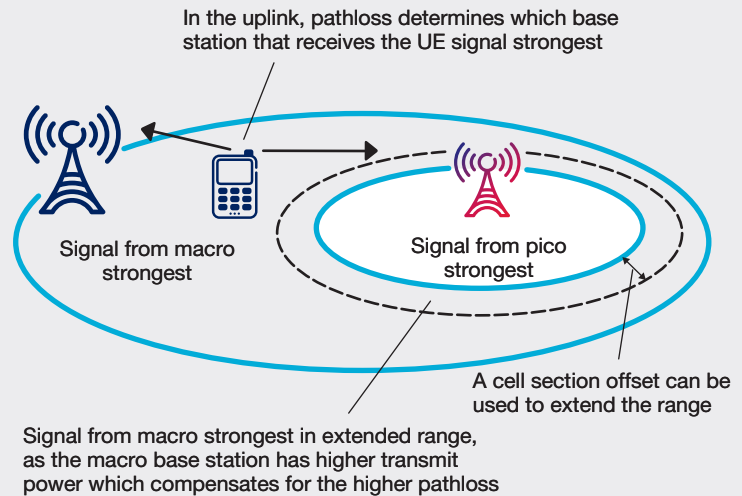
User behavior and traffic – 6,000 subscribers per sq. km, 80 percent in indoor clusters (250 per sq. km), file transfer, 6 percent of daily traffic during busy hour

Deployment and propagation

– Urban environment, macro ISD 425m or 300m, clusters deployed with low power nodes in order of traffic volume

System – HSPA in 10 or 20MHz, antenna configuration DL 2x2, UL 1x2, macro power 46dBm, pico power 30dBm

FIGURE 3 Cell selection in a heterogeneous network



closer to the macro users than their serving macro base station and consequently, the pico base stations receive better-quality UE signals. There are different flavors of cooperation schemes, such as coordinated scheduling, coordinated beamforming, as well as joint transmission and reception.

With coordinated beamforming, a reduction of the interference caused to a non-served user can be achieved by using an appropriate base station antenna pattern: a so-called beam. Due to their loose backhaul capacity and latency requirements, simplified coordinated beamforming schemes can be applied in a distributed pico-macro setup. However, such schemes offer the highest potential in a centralized RRU

deployment that enables more elaborate optimization algorithms.

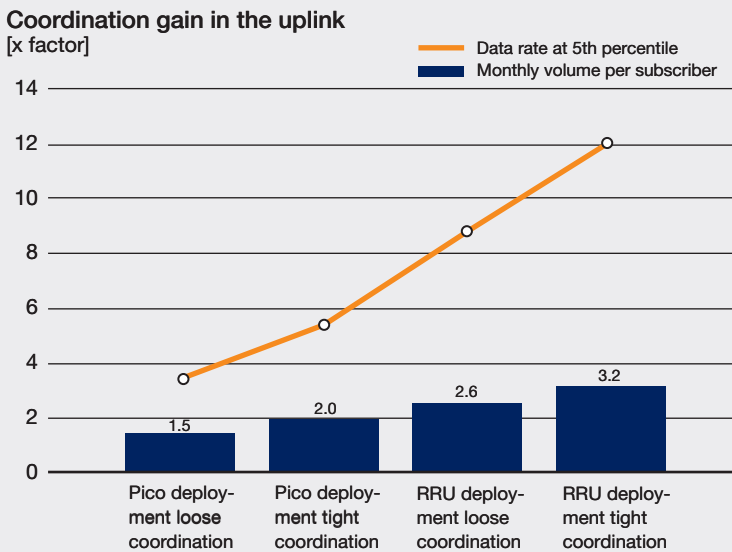
Joint transmission-based cooperation refers to simultaneous transmission from different nodes to the same user. To achieve a coherent overlap of the signals at the receiver, the transmitters must be tightly synchronized in time and frequency. While transmitters can easily reach the required synchronization level in an RRU deployment, additional synchronization equipment at each node (such as a GPS receiver) is needed in a distributed pico-macro setup. Therefore, joint transmission is more easily applied in an RRU deployment.

There are diverse joint-reception schemes in the UL, based on

Table 1: Rules of thumb for low power node deployment

Design choice	Decision criteria
Access Open access Closed subscriber group	Deployment conditions Operator deployed User deployed
Deployment Indoor deployment Outdoor deployment	Hotspot spread and position Large indoor hotspot Outdoor hotspot or many smaller indoor hotspots
Type of low power node RRU Conventional pico Relay	Backhaul availability Fiber (P2P or WDM/PON) Copper / fiber / microwave No backhaul
Frequency reuse Reuse macro spectrum Separate spectrum	Capacity need and access Capacity is driver Closed subscriber group
Power and cell selection Power Biased cell selection	Hotspot area Cover the hotspot* Cover the hotspot* *value varies significantly

FIGURE 4 Coordination potential with two low power nodes in each macro cell cooperating with the macro base station, ISD 425m, 20MHz bandwidth, 1x2 antennas



more-or-less extensive information exchange between nodes. For WCDMA, the basic functionality of soft and softer handover represents a form of joint reception. In LTE, joint-reception schemes should preferably be applied in a network with a low-latency backhaul as the synchronous uplink HARQ has strict timing requirements.

Compared to a heterogeneous deployment with stand-alone nodes, coordinated pico and RRU deployments enable straightforward optimization of joint-reception and joint-scheduling schemes. Examples of achievable gains are shown in **Figure 4**. Both data rates and capacity (achievable monthly volume per subscriber) can be improved. The figure shows an increase in monthly volume by a factor of 3.2 with a tight RRU deployment compared to an uncoordinated heterogeneous deployment for a fixed required fifth percentile data rate of 0.5Mbps. Alternatively, for a fixed monthly volume per subscriber of 7GB, the improvement in the fifth percentile data rate reaches a factor of 12 with a tight RRU deployment.

Conclusion

Mobile-broadband traffic is increasing. In parallel, new applications are raising

expectations for higher data rates in UL and DL. Creating a heterogeneous network by introducing low power nodes is an attractive approach to meeting traffic demands and performance expectations, particularly in situations where traffic is concentrated – in hotspots, or areas that cannot be suitably covered by the macro layer. By combining low power nodes with an improved and densified macro layer, very high traffic volumes and data rates can be supported. The nature of the existing network, as well as technical and economic considerations, will dictate which approach – improving the macro layer; densifying the macro layer; or adding pico nodes – or combination of approaches best meets volume and data-rate targets.

Low power nodes give high data rates locally and also offer benefits to macro users by offloading and cooperating with the macro layer. Tight integration of low power nodes with the macro network provides gains over the uncoordinated case through favorable combining of received signals and avoiding interference.

Fredric Kronestedt



joined Ericsson in 1994 to work on radio access network research. Since then, he has worked in many different roles, including GSM system design and management. He is currently working at Business Unit Networks', Development Unit Radio Systems and Technology, where he is a project manager working in close cooperation with network operators to analyze mobile broadband performance in real networks. Fredric holds an M.Sc. in electrical engineering from the Royal Institute of Technology (KTH), Sweden.

Laetitia Falconetti



is a research engineer in the Radio Protocols and Multimedia Technologies Group at Ericsson Research, Aachen, Germany. Her research interests include interference management for LTE and energy-efficient mobile communications. Recently, her work has focused on suitable interference management techniques for heterogeneous LTE networks. She received an M.Sc. in electrical engineering from Karlsruhe University (KIT) in Germany in 2006. Before joining Ericsson in 2008, she was part of the 3GPP delegation of Rohde & Schwarz in Munich, Germany.

Anders Furuskär



is a principal researcher within the field of Wireless Access Networks at Ericsson Research. His current focus is HSPA and LTE evolution to meet future data rate and traffic volume demands. Anders holds an M.Sc. and a Ph.D. from KTH, Sweden. He joined Ericsson in 1990.

Klas Johansson



is a system engineer at Ericsson's WCDMA Systems Management in Kista, Sweden. He received his Ph.D. in telecommunications from KTH, Sweden in 2007 with a dissertation on cost-effective deployment strategies for heterogeneous wireless networks. He joined Ericsson in 2008, and has led different activities related to HSPA evolution, including multi-carrier HSPA and the evolution of the enhanced uplink (EUL). He is currently a coordinator of heterogeneous network activities for HSPA.

Sara Landström



is an experienced researcher at Ericsson Research in Luleå, Sweden. Her research area is Wireless Access Networks and her current focus is LTE-based heterogeneous networks. She joined Ericsson in 2008 after receiving her Ph.D. in computer networking from Luleå University of Technology, Sweden.

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