Adaptive behaviour of some simple algorithms in LTE-Wifi Heterogeneous Networks

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Abstract— **This paper evaluates the dynamic behaviour of WiFi and LTE heterogeneous network (HetNet), based on computer simulations. The basic modelling abstraction to describe system operation is described along with the necessary numerical parameters. The focus is on admission control and network reselection in HetNets; two simple but practical algorithms are described and their performance in terms of absolute system throughput is shown and compared to an LTE only scenario. Results show that system throughput can be increased if network-controlled admission control is applied against simple user-controlled algorithms. The impact of interfering Access Points is also inspected. It is shown that adaptation is a crucial task while operating in a license-free band.**

Keywords—heterogeneous networks, network management algorithms, cell capacity, wifi, lte

I. Introduction

As the number of the mobile internet subscriptions and the user needs are growing nowadays, the mobile operators have to take advantage of every possibility to increase the network capacity in their system. Cellular network capacity can be extended by means of increasing spectral efficiency, increasing used bandwidth or network densification.

Using heterogeneous networks (HetNets) is an opportunity to increase capacity as this approach utilizes more bandwidth and denser network. HetNets usually consist of several sub-networks with (possibly) different radio access technologies (RATs), with multiple, overlapping cellular coverage layers. That is typically an overlay macrocell network that provides ubiquitous coverage and an underlying micro- or picocell network that provides extra capacity for traffic hotspot areas. However, in this paper we use the term HetNet for any cellular layout, that contain more than one technology and different cell sizes. Also, we assume that an operator owns and is in full control of the devices that create the cellular HetNet.

A particular example is LTE-WiFi HetNets, which include LTE base stations (eNB, enhanced Node B) and WiFi access points (AP) as well. This is graceful because the system escalates the bandwidth in the ISM (industrial, scientific and medical) band that can be used license-free. A user can be served in both subsystems, depending on the technologies that the mobile equipment can use. The throughput of these systems is roughly the sum of the subsystems' throughputs.

Combining LTE networks with WiFi networks is particularly good option because smart phones can also attach to WiFi networks, so users do not need to buy new equipments to use this network. Moreover, there are commercial solutions available that enable SIM (Subscriber Identity Module) card based authentication over operator-owned WiFi network; so service providers can enable access to their network over any RAT, using the same authentication mechanisms.

Using LTE-WiFi HetNet of course results in technical problems besides the advantages. First of all, WiFi uses licence free frequency band, therefore the operator is no longer in full control of its used spectrum. Unlike HetNets in licensed bands (e.g. LTE-HSPA), it is possible that an interferer (another WiFi AP) is turned on anywhere and anytime in the network. Providing carrier grade network access and Quality of Service (QoS) in such a dynamic, interference rich environment is a challenge.

Another technical difficulty is the optimal radio resource management in HetNet systems. The network needs more complex control algorithms that on one hand distribute radio resources of a cell among mobiles served by that cell; on the other hand mechanisms are necessary that determine which RAT should serve a given traffic flow (admission control) and if required, forces a flow into another cell and/or radio technology (vertical handover).

In this paper we investigate this second problem area. Namely we show absolute performance results in terms of system throughput for cellular systems jointly operating LTE and WiFi interfaces. Our examinations focus on the admission control and data session re-scheduling (vertical handover) in such HetNets.

II. System model and resource allocation methods

A. System model

We suppose that the LTE-WiFi HetNet consists of WiFi-capable LTE base stations which soon will be available on the market [1]. This means that WiFi APs and LTE eNBs are integrated in the same hardware, so they are at the same locations. This solution has the advantage of not requiring additional infrastructure and backhaul connections and existing sites can be further utilized and capacity boosted with moderate additional cost. However, in this architecture the WiFi APs are not freely placed, rather should be looked at as capacity boosters for LTE sites.

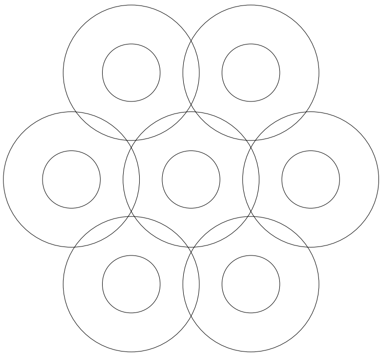

Figure 1. Basic architecture of the network

Figure 1. shows the structure of the investigated system. The common LTE-WiFi sites are located in a standard hexagonal grid. We assume that such a layout is the result of an existing network, extended by WiFi upgrade of base stations. In our model generally WiFi APs may use less power and are deployed in higher frequency band with worse propagation conditions, hence WiFi APs have smaller coverage. Accordingly, the big circles show the coverage of LTE cells and the small circles illustrate the WiFi coverage. It is noticeable that there is no WiFi coverage in a certain amount of area, so the users around cell edge cannot attach to the WiFi system.

We assume that an admission control mechanism is present in the system that determines the serving interface for all mobile terminals. The flow chart of the admission controller is in Figure 2.

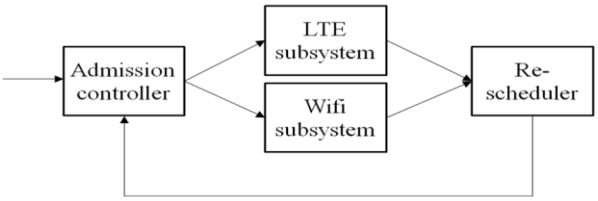

Figure 2. Admission controller flow chart

Arriving communication sessions are served by LTE or WiFi subsystem depending of the admission control algorithm. We assume that the algorithm can monitor the utilization of the two subsystems and have to decide:

- to reject the session
- to admit the session and to which subsystem.

In our approach the decision is based on the signal to interference plus noise ratio (SINR) and the utilization of the two subsystems.

As the SINR can change over time due to the dynamic nature of the system, we assume that a re-scheduling mechanism is present to decide whether vertical handovers are necessary. In our approach it is performed basically as a new admission control decision for on-going sessions, as if they were newly initiated sessions. The re-scheduling can be regular or occasional. Later in this paper we evaluate the effect of re-scheduling mechanism in the system.

B. *Basic algorithms*

In today's smartphones popular operation systems the network selection is usually very straightforward, if WiFi is available, mobile attaches to it (even if it is worse from bitrate point of view). This method is evaluated in our work and referred to as "preferred WiFi" method.

Another algorithm is the "always best" approach, which determines the achievable bitrate for a session, based on the detailed model shown in the next paragraph, and assigns the session to the network where it will receive better performance. As a baseline we evaluate the LTE only case as well. This assumes that all mobiles are always served by LTE. We chose this as baseline in order to be capable of describing the absolute gain in terms of throughput, when an operator considers the WiFi extension. We are aware of the fact that naturally more bandwidth introduced by WiFi results in more throughput, therefore spectral efficiency could be a measure in another evaluation, however, again, we are interested in absolute gain.

III. APPLIED NUMERICAL MODEL

This Section provides some more detailed information on the applied numerical model used to investigate the resource management methods.

A. *LTE subsystem*

In the LTE subsystem the transmission rate depends on the technology used and the SINR of the mobile station.

The technology determines the effective symbol rate and the information that a symbol can carry. In LTE there is an Adaptive Modulation and Coding (AMC) scheme that conforms to the SINR, binding via the Channel Quality Indicator (CQI). The higher CQI means higher achievable bit rate. The typical values in LTE [2][3] are shown in TABLE I.

TABLE I. THE SNR-CQI BINDING WITH EFFECTIVE BIT RATE

CQI	Min. SNR (dB)	Modulation	Useful bits/symbol (μ)	Carrier rate (bit/s)
0	no transmission			
1	-6.25	QPSK	0.1523	24368
2	-4.34	QPSK	0.2344	37504
3	-2.43	QPSK	0.3770	60320
4	-0.52	QPSK	0.6016	96256
5	1.39	QPSK	0.8770	140320
6	3.30	QPSK	1.1758	188128
7	5.21	16QAM	1.4766	236256
8	7.12	16QAM	1.9141	306256
9	9.03	16QAM	2.4063	385008
10	10.94	64QAM	2.7305	436880
11	12.85	64QAM	3.3223	531568
12	14.76	64QAM	3.9023	624368
13	16.67	64QAM	4.5234	723744
14	18.58	64QAM	5.1152	818432
15	20.50	64QAM	5.5547	888752

The LTE physical resource block contains 160 000 useful symbols per second, so the transfer rate of a PRB can be computed for every mobile as:

$$Rate(x,y) = \mu(SINR(x,y)) \cdot 160000 \qquad (1)$$

The bandwidth determines the number of PRBs (Physical Resource Blocks). In our model we assume 10 MHz deployment which is often the case for LTE nowadays. It means that there are 50 PRBs in the frequency domain.

In our model we assume that Round Robin scheduler is applied in the LTE cell, meaning that the PRBs are allocated equally among the mobile terminals, so the average data rate can be calculated as:

$$AvgRate_{LTE} = \frac{1}{n} \cdot \sum_{i=1}^{n} Rate(i) \cdot n_{PRBs} \qquad (2)$$

where Rate(i) is data rate for the i-th mobile equipment, n is the number of active mobiles in the LTE subsystem, n_{PRBs} is the number of PRBs in the cell.

TABLE II. THE LTE SUBSYSTEM MODEL PARAMETERS

Transmission power (P_{TX})	1 W
Cell radius (R)	500 m
Carrier frequency (f)	1800 MHz
Bandwidth (B)	10 MHz (FDD)
Number of PRBs (n_{PRBs})	50
Height of base station (h_{BS})	30 m
Height of mobile station (h_{MS})	1.5 m

B. *WiFi subsystem*

In the WiFi subsystem there is no central scheduling in distributed channel access mode, so the mobile stations have to compete for the channel. Because of the collision avoidance algorithm is based on incremental back-off method, the utilization of the channel can be calculated from the Markov chain described in [4] in case of full buffer model:

$$S = \frac{P_s P_{tr} E[P]}{(1-P_{tr})\sigma + P_{tr} P_s T_s + P_{tr}(1-P_s)T_c} \qquad (3)$$

where P_S is the probability of a successful transmission of a mobile, P_{tr} is the probability of the transmission is the channel, E[P] is the average packet transmission time, σ is the slot time, T_S is the average time the channel sensed busy because of a successful transmission and T_C is the average time the channel is sensed busy by each station during a collision. Furthermore, parameters of the above expression can be determined as [4]:

$$P_{tr} = 1-(1-\tau)^n \qquad (4)$$

$$P_s = \frac{n\tau(1-\tau)^{n-1}}{P_{tr}} \qquad (5)$$

where n is the number of stations in the system, and τ is the probability that a station transmits in a randomly chosen slot time, and can be calculated from the collision probability (p), which depends on the size of the initial congestion window (W), and from the maximum back-off stage (m). The relation is shown in Figure 3.

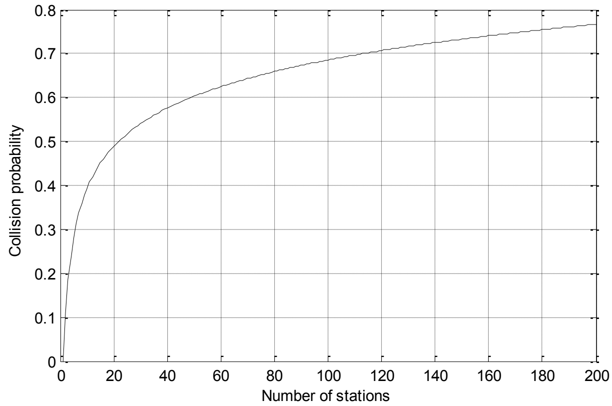

Figure 3. Collision probability - W=15, m=6

Because of uniform packet size, the transmission time of an average packet (E[P]) depends on the Modulation and Coding Scheme (MCS) used by the stations. The 802.11a standard [5] describes 8 different modulation and coding schemes, shown in TABLE III.

TABLE III. MODULATION AND CODING SCHEMES IN 802.11A NETWORK

Modulation	FEC	Bit rate (Mbit/s)	Packet time (1500 B)	Required SINR (dB)[6]
BPSK	1/2	6	2000 µs	14
BPSK	3/4	9	1333 µs	15
QPSK	1/2	12	1000 µs	16
QPSK	3/4	18	667 µs	18
16-QAM	1/2	24	500 µs	22
16-QAM	3/4	36	333 µs	26
64-QAM	2/3	48	250 µs	29
64-QAM	3/4	54	222 µs	31

T_S and T_C can be calculated with RTS/CTS (Request-To-Send/Clear-To-Send) access method:

$$T_S = RTS + 3 \cdot SIFS + 3 \cdot \delta + CTS + H + E[P] + ACK + DIFS \qquad (6)$$

$$T_C = RTS + DIFS + \delta \qquad (7)$$

The average data rate can be calculated as:

$$AvgRate_{Wifi} = \frac{S}{E[P] \cdot n} \cdot 1472 \cdot 8bit \qquad (8)$$

TABLE IV. THE WIFI SUBSYSTEM PARAMETERS IN CALCULATION [5]

PHY header time (H)	20 µs
RTS packet time (RTS)	H+64 µs (224 + 160 bit payload)
CTS packet time (CTS)	H+56 µs (224 + 112 bit payload)
ACK packet time (ACK)	H+56 µs (224 + 112 bit payload)
SIFS time (SIFS)	16 µs
DIFS time (DIFS)	34 µs
propagation delay (δ)	1 µs
slot time (σ)	9 µs
Congestion window (W)	15
Maximum back-off stage (m)	6
Transmission power (P_{TX})	100 mW
Carrier frequency (f)	5200 MHz
Bandwidth (B)	20 MHz (TDD)
Packet size	1500 byte (28 + 1472 byte)

IV. RESULTS

The results were calculated in a static simulator. The mobile equipments were distributed uniformly in the cell. They all can use the LTE and the WiFi radio access technology. According to a simple traffic model, they stay in place, and in connected state they always want to download from the base station. This full buffer model is similar for example to multimedia downloading, where big files are being downloaded from a server.

We analyse system performance based on simulations, whose parameters are described above. Three basic operations are chosen, according to previous description: LTE only as baseline, always best and preferred WiFi methods. We look at system throughput as absolute performance indicator.

A. Arriving of the mobile stations

We were interested in transient behaviour as well, so the first simulation shows the ramping up of HetNet system. The mobile sessions arrive according to a Poisson process with mean 1 per second. The number of mobile stations increases from 0 to 100. The spatial distribution of the mobile stations is uniform in the LTE cell area.

Results seen are achieved as average based on multiple simulations. The results come from the average of 10000 static simulations, where mobile equipments remain in initial place.

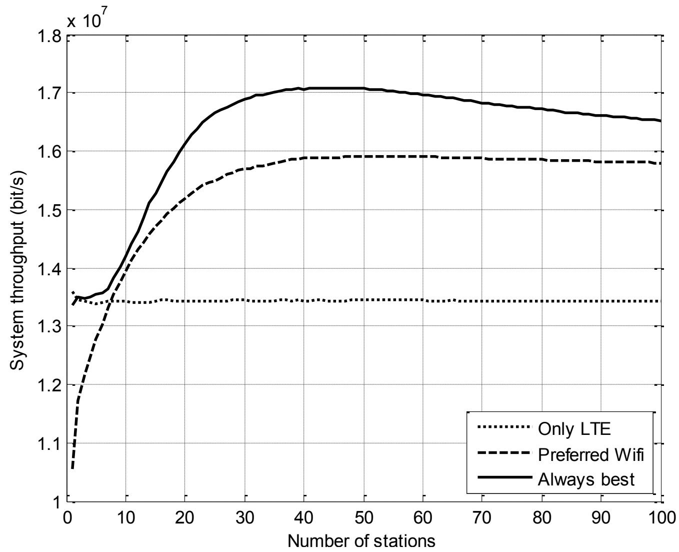

Figure 4. Arriving mobile stations – without re-scheduling

As we expected, Figure 4. shows that with only the LTE subsystem, the average system throughput is permanent, because the capacity of the base station is distributed evenly by the round robin scheduler among the increasing number of mobile equipments. If the preferred WiFi approach is used, we can see the gain coming from the more bandwidth used in total. For low number of mobiles however, there is high probability that WiFi, although accessible, provide much worse performance than LTE, resulting in lower system throughput. For higher number of mobiles this effect is vanished by the gain achieved by mobiles under good WiFi coverage. Always best method outperforms preferred WiFi access in all cases.

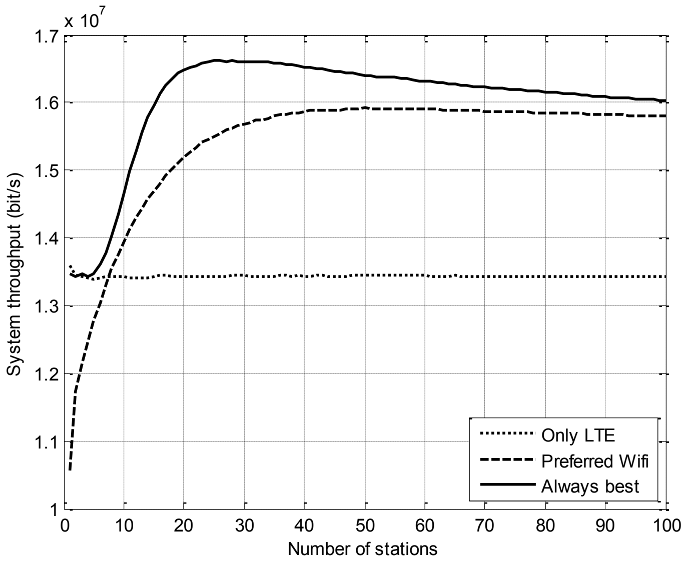

Figure 5. Arriving mobile equipments – with re-schedule

Figure 5. shows the arriving mobile equipments in the case when there is re-scheduling in the system. The algorithm send the mobile stations back to the admission controller after 5 seconds after the arriving, so the mobile stations can be adapted to the changing conditions. The result is the same as above.

B. Leaving of the mobile stations

In these examinations initially there are 100 mobile stations and they leave one-by-one from the network with exponentially distributed time difference with mean 1 second.

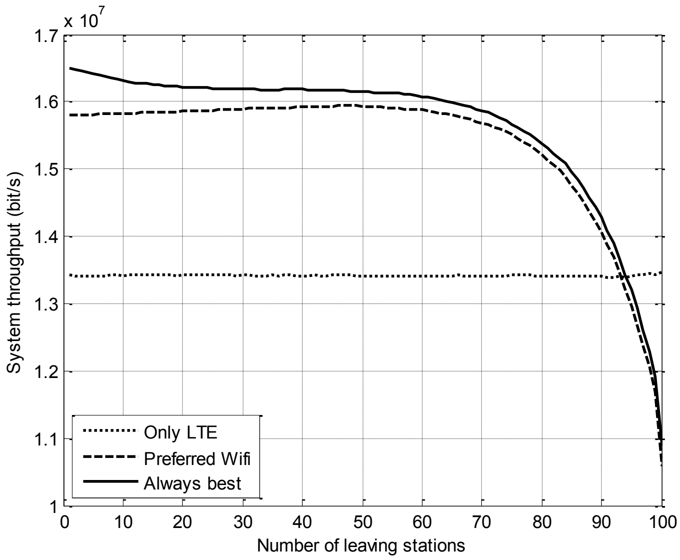

Figure 6. Leaving mobile equipments – without re-schedule

Figure 6 shows the first case without re-scheduling. It can be seen that in case of Preferred WiFi and Always Best algorithms, the system throughput is decreasing. That is because of the use of the WiFi system, where the throughput cannot increase as much as the number of users decreases.

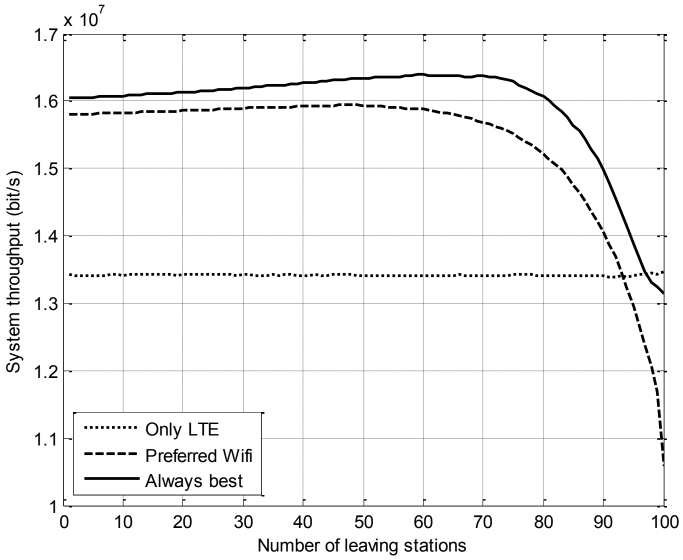

Figure 7. Leaving mobile equipments – with re-schedule

In Figure 7 the Preferred WiFi algorithm cannot increase the system throughput because the users in the WiFi subsystem will stay there despite of the re-scheduling, but the Always Best algorithm put them to the LTE system, so the system throughput can be higher than with the other algorithms.

C. Switching on interfering Access Points

In this case there are 100 users in the cell, and initially there is no interfering Access Point in the cell, but they are being switched on sequentially. Time difference between the turning on of two interfering APs is chosen according to exponential distribution with expected value 10 seconds.

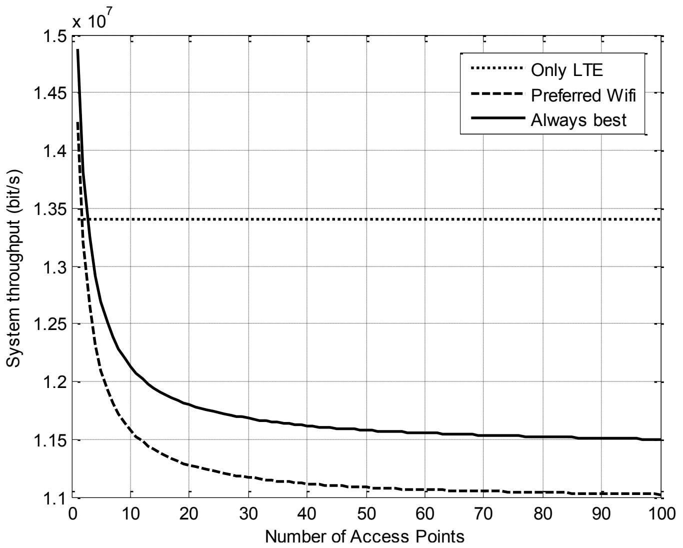

Figure 8. Interfering Access Points – without re-schedule

Figure 8 shows that without adapting to environmental changes, the Preferred WiFi and Always Best algorithms cannot keep up with the throughput of the Only LTE scheme, they break down very quickly. The mobile equipments are got stuck in the continuously worsening WiFi subsystem.

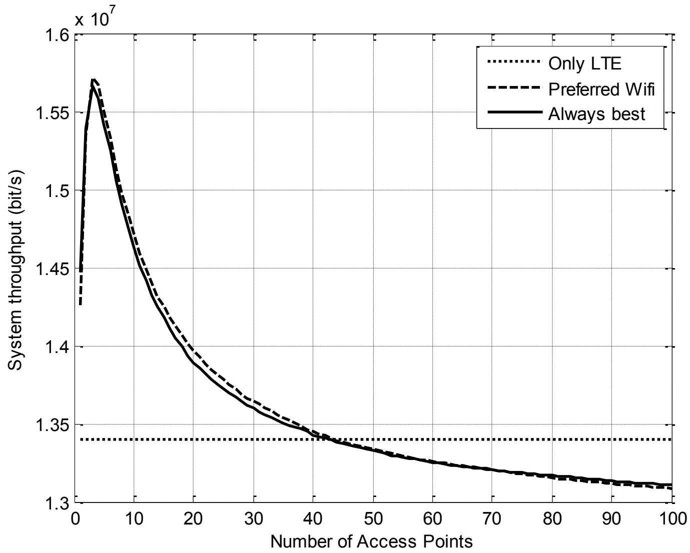

Figure 9. Interfering Access Points – with re-schedule

Figure 9 shows that with re-scheduling, they also can adapt to the environmental changes, the mobile stations get to put over to the LTE subsystem, so the interfering WiFi cells do not deteriorate the system throughput so much as in the former case. After the first few interfering Access Points arrive, the average packet length of the stations gets larger, the ratio of useful transmission increases. After adding more disturbing APs, the system throughput decreases because of the departing stations from the WiFi subsystem.

V. CONCLUSIONS

It has been shown that Heterogeneous Networks (HetNets) can efficiently expand the limited capacity of singular networks. This paper also shows that new admission control algorithms have to be developed. With WiFi subsystem it is also important to take into account that this works in license-free band; anyone can switch on other devices, so algorithms must adapt to the environmental changes.

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