Improving Multimedia Transmission in 3G Wireless NetworksUsing Cooperative Diversity Technique

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ABSTRACT
To effectively combat multipath fading across multiple protocol layers in 3G wireless networks during transmission of multimedia components like image and video, we develop energy efficient transmission protocol called cooperative diversity which involves cooperation among terminals and which is created by antenna sharing and coordinated transmission by several distributed radios. A Cooperative diversity network with a sender, a destination and a third station acting as a relay is analyzed. The channels are modeled containing thermal noise, Rayleigh fading and path loss. After summarizing a model for the wireless channel we enhance the basic arrangement to a system with several relay and receiver stations and we present various practical algorithms based on the relaying process that are 1) Amplify and Forward (AAF), 2) Decode and Forward (DAF). To combine the incoming signals the channel quality should be estimated. Information about the average quality shows nice benefits and a rough approximation about the channel quality increases the performance even more. The combining techniques used here are 1) Signal to Noise Ratio Combining (SNRC) and 2) Enhanced Signal to Noise Ratio Combining (ESNRC). An image is taken as multimedia information to be transmitted and is received under variety of conditions and the performance is evaluated.

Keywords
Multimedia, diversity, Co-operative diversity, relay, combining

1. INTRODUCTION
Cooperative communication is one of the fastest growing areas of research,and it is likely to be a key enabling technology for efficient spectrum use in future. The key idea in cooperation is that of resource-sharing among multiple nodes in a network. The reason behind the exploration of user-cooperationis that willingness to share power and computation with neighboring nodescan lead to savings of overall network resources. Mesh networks provide anenormous application space for user-cooperation strategies to be implemented. In 3G wireless transmission the quality of multimedia signal suffers severe degradations due to effects like signal fading caused by multipath propagation. To reduce such effects, diversity is proposed that can be used to transfer the different samples of the same signal over essentially independent channels.

1.1 Diversity :
Diversity is a powerful technique transmitting the redundant signals over essentially independent channel realizations in conjunction with suitable receiver combining to average channel effects.

1.2 Spatial Diversity:
Spatial diversity combats multipath fading by transmitting copies of original signals through uncorrelated paths to the receiver. Signals are combined at the receiver end and the individual channel effects are averaged in spatial diversity.

Antenna arrays are the most common way to achieve spatial diversity. But multiple antennas are not always available or the destination is just too far away to get good signal quality. So the cooperative diversity technique is necessary to overcome this problem. Spatial diversity employs multiple antennas, usually with the same characteristics, that are physically separated from one another. Depending upon the expected incidence of the incoming signal, sometimes a space on the order of a wavelength is sufficient.

1.3 Cooperative Diversity:
An energy efficient class of cross layer network algorithm called co-operative diversity that exploit the broad cast nature of the wireless medium and spatial diversity of the channel. Co-operative diversity is a fruitful technique which relies on the co-operation on multiple spatially distributed nodes, provides a useful alternative for fading mitigation.
Owing to the broadcasting nature of the wireless medium transmission from the source node may be heard by the node in neighborhood. These neighborhood nodes may act as wireless relays and provide alternative communication routes that give raise to co-operative networks.Cooperative diversity is a cooperative multiple antenna techniques which exploits user diversity by decoding the combined signal of the relayed signal and the direct signal in wireless multihop networks.
A conventional single hop system uses direct transmission where a receiver decodes the information only based on the direct signal while regarding the relayed signal as interference, whereas the cooperative diversity considers the other signal as contribution. That is, cooperative diversity decodes the information from the combination of two signals. Hence, it can be seen that cooperative diversity is an antenna diversity that uses distributed antennas belonging to each node in a wireless network.

2. DIRECT LINK TRANSMISSION :
The block diagram of system model for a single link transmission considers the modulator (source), channel and demodulator (destination) as illustrated in the Fig 1.

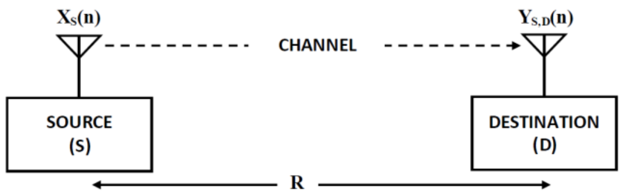

Fig 1: Block diagram of single link transmission model

Here R is the distance between source and destination and $X_s(n)$ is the Signal transmitted by the source and $Y_{s,d}(n)$ is the Signal received by the destination. Two models are considered for the single link transmission. They are Signal model and Channel model [1].

2.1 Signal Model:

An image signal shown in Fig 4 is considered as the multimedia signal and is modeled. Intensities of each and every pixel of this image are taken as the samples. These samples are encoded by binary coding since binary code withstands a relatively high level of noise immunity and it is a convenient method to express the ordinal number (pixel intensity) of the representation level as a binary number. To facilitate the digital transmission BPSK (Binary Phase Shift Keying) [3,9] modulation technique is applied to the encoded bit streams. Binary phase shift keying is a modulation technique in which binary symbols 1 and 0 modulate the phase of the Carrier [9].For bit '1' a symbol '1' that is the same carrier is transmitted without any phase shift. For bit '0' a symbol '-1' that is the inverted carrier is transmitted with a phase. At the receiving end the bit streams are then decoded and the image is retrieved.

2.2 Channel Model:

In a 3G wireless network, the data which is transferred from a sender to a receiver has to propagate through the air. During propagation several phenomena will distort the signal. The channel consists of path loss andRayleigh fading which are multiplicative components and thermal noisewhich is additive. [1, 2].

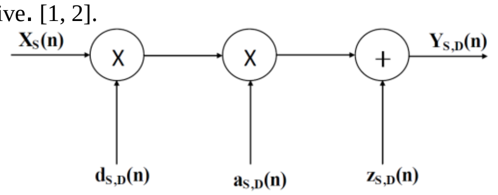

Fig2:Channel Model

In the channel model shown in Fig 2 the transmitted signal $X_s(n)$ is attenuated by the path loss $d_{S,D}$ having fading coefficient $a_{S,D}(n)$ and disturbed by Additive white Gaussian noise $Z_{S,D}(n)$ and received as signal $Y_{S,D}(n)$ at the receiver.

2.3 Path loss, Fading and Noise:

Path loss (or) path attenuation is the reduction in power densityof an electromagnetic wave as it propagates through space.Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption.Path loss is inversely proportional to the square of the distancebetween the source(S) and the destination (D). It is given by

$$d_{S,D} \alpha \frac{1}{R^2} \qquad (1)$$

Fading is the distortion that a carrier-modulated telecommunication signal experiences over certain propagation media. In wireless systems, fading is due to multipath propagation and is sometimes referred to as multipath induced fading. The fading coefficient $a_{S,D}$ can be modeled as a zero mean complex Gaussian random variable.

The signal is attenuated mainly by the effects of free-space path loss andfading. Therefore the attenuation factor $h_{S,R}$ is given by

$$h_{S,D} = d_{S,D} a_{S,D} \qquad (2)$$

The main sources of noise in a wireless network are interference and electronic components like amplifiers. If the latter dominates, thermal noisecan be assumed, which can be characterized as additive complex Gaussiannoise. The scalar $z_{S,D}(n)$ can then be simulated as the sum of a real anda imaginary noise vector, both Gaussian distributed, mutually independentand zero mean with variance σ_n^2. The total noise power can be denoted by $N_0 = 2\sigma_n^2$.

2.4 Signal to Noise Ratio:

The ratio of the amplitude of the desired signal to the amplitude of noise signals at a given point in time. The Signal to noise ratio (SNR) is a widely used value to indicate the signal quality at the destination.

$$SNR = \left(\frac{S}{N_0}\right) = \frac{|h_{S,R}|^2 \varepsilon}{N_0} \qquad (3)$$

Where$h_{S,R}$is the attenuation factor for the path between the source and relay node and$\varepsilon$is transmitter power and N_0isnoise power.

2.5 Bit error Rate:

Bit error rate also called as probability of error is the ratio of the number of bits, elements, characters, or blocks incorrectly received to the total number of bits, elements, characters, or blocks sent during a specified time interval.

The signal quality received at the destination depends on the SNR of the channel and the way the signal is modulated. The probability of a bit error due to Rayleigh fading is given by

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}_b}{1 + \bar{\gamma}_b}}\right) \qquad (4)$$

Where$\bar{\gamma}_b$ denotes the average signal-to-noise ratio.

3. MULTIHOP TECHNIQUE

There are several approaches to implement diversity in a wireless transmission. Multiple antennas can be used to achieve space and/or frequency diversity. But multiple antennas are not always available or the destination is just too far away to get good signal quality.

To get diversity, an interesting approach might be to build another mobile station as a relay. The model of such a system is illustrated in Fig 3. The sender S sends the data to the destination D, while the relay stationR is listening to the transmission. The relay sends the received data burstafter processing to the destination as well, where the two received signalsrecombined. As proposed in [4], orthogonal channels are used for the two transmissions.

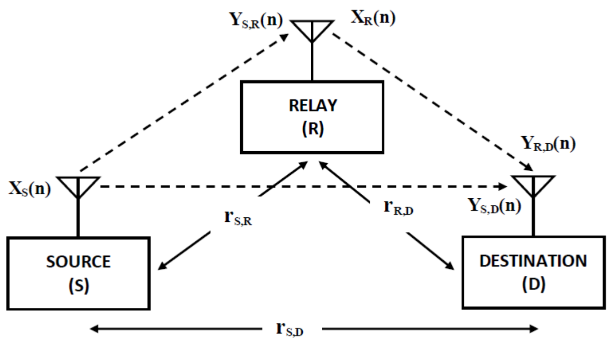

Fig 3: Cooperative Diversity – Block Diagram

In Fig 3$r_{S,D}$ is the distance between source and destination, $r_{S,R}$ is the distance between source and relay, $r_{R,D}$ is the distance between relay and destination, $Y_{S,D}(n)$ is the signal received by the relay from the source, $X_R(n)$ is the signal transmitted by relay and $Y_{R,D}(n)$ is the signal received by the destination from the relay

At time slot-1 the source sends its message to both the relay and destination that is the source broadcasts its message.Let X_s (n) is the signal transmitted by the source to relay and destination.

Signal received by the Relay due to the transmission of the Source is given by

$$Y_{S,R}(n) = h_{S,R}(n)X_S(n) + Z_{S,R}(n) \quad (5)$$

Where the attenuation $h_{S,R}(n)$ is the product of path loss and fading coefficient of the channel between the source and relay, that is $h_{S,R}(n) = d_{S,R}h_{S,R}(n)$. Signal received by the Destination due to the transmission of the Source, can be calculated as

$$Y_{S,D}(n) = h_{S,D}(n)X_S(n) + Z_{S,D}(n) \quad (6)$$

Where $h_{S,D}(n)$ is the attenuation factor.

At time slot 2 the relay sends the message to the destination with the help of the relaying protocols such as amplify and forward(AAF) and decode and Forward(DAF), During this time slot the sender must by silent.Let $X_R(n)$ be the signal transmitted by the relay to the destination.Signal received by the Destination due to the transmission of the Source

$$Y_{R,D}(n) = h_{R,D}(n)X_S(n) + Z_{R,D}(n) \quad (7)$$

4. RELAYING PROTOCOL

Cooperative relaying allows single-antenna terminals to gain some benefits of transmit diversity without the need for physical antenna arrays. Cooperative relaying (with one relay) includes two phases where the first one is for the transmission of the source and the second for the relaying of the relay, thus significantly reducing spectral efficiency. The cooperative transmission protocols used in the relay station areAmplify and forward (AAF) and Decode and Forward (DAF) [1, 2].

4.1 Amplitude and Forward:

This method is often used when the relay has only limited computing time or power available or the time delay, caused by the relay to decode and encode the message, has to be minimized. The idea behind the AAF protocol is simple. The signal received by the relay was attenuated and needs to be amplified before it can be sent again. In doing so the noise in the signal is amplified as well, which is the main downfall of this protocol.The incoming signal is amplified block wise. Assuming that the channel characteristic can be estimated perfectly, the gain for the amplification can be calculated as follows.

$$E[|Y_R|^2] = E\left[|h_{s,R}|^2\right] E[|X_S|^2] + E\left[|Z_{S,R}|^2\right] \quad (8)$$

$$E[|Y_R|^2] = |h_{s,R}|^2 \varepsilon + 2\sigma_{S,R}^2 \quad (9)$$

WhereE[$|Y_R^2|$] is power of the received signal, E[$|h_{S,R}^2|$] = $|h_{S,R}^2|$ isthe strength of the attenuation, E[$|X_S^2|$] = ε is the power of transmitted signal E[$|Z_{S,R}^2|$] = $2\sigma_{S,R}^2$ is strength of AWGN.

The Power Gain of the relay node is given by

$$\text{Power Gain} = \sqrt{\frac{\text{Power transmitted}}{\text{Power received}}} \quad (10)$$

$$\beta = \sqrt{\frac{\varepsilon}{|h_{s,R}|^2 \varepsilon + 2\sigma_{S,R}^2}} \quad (11)$$

- AAF relay does not suffer from decoding errors that can cause errors in the coded signal.
- It achieves maximum diversity.
- The noise gets amplified along with the data.

4.2 Decode and Forward:

Nowadays a 3G wireless transmission is very seldom analogue and the relay has enough computing power, so Decode and Forward technique is most often the preferred method to process the data in the relay. The received signal is first decoded and then re-encoded. So there is no amplified noise in the sent signal, as is the case of using the AAF protocol.

The relay can decode the original message completely. This requires a lot of computing time, but has numerous advantages. If the source message contains an error correcting code, received bit errors might be corrected at the relay station. Or if there is no such code implemented a checksum allowsthe relay to detect if the received signal contains errors. Depending on the implementation an erroneous message might not be sent to the destination.

But it is not always possible to fully decode the source message. The additional delay caused to fully decode and process the message is not acceptable, the relay might not have enough computing capacity or the source message could be coded to protect sensitive data. In such a case, the incoming signal is just decoded and re-encoded symbol by symbol

- DAF relay does not suffer from the noise amplification as does the AAF relay. It achieves maximum diversity.
- A relay station transmits a Negative Acknowledgement (NACK) signal to a source station if a signal received from the source station is found to contain errors during decoding by the relay station.
- Not scalable to large cooperating groups

5. COMBINING METHODS

As soon as there is more than one incoming transmission with the same burst of data, the incoming signals have to be combined. The signals are combined only with the current information of the signal and channel. The two combining methods used are Signal to Noise ratio and Enhanced Signal to noise ratio [1, 4, and 6].

5.1 Signal to Noise Ratio Combining(SNRC):

An even better performance can be achieved when precise information about the current state of the different channels is known. An often used value to characterize the quality of a link is the SNR, which is used to weight the received signals.

The estimation of the SNR of a multi-hop link using AAF or a direct link can be performed by sending a known symbol sequence in every block. This sequence is used to estimate the phase shift as well. If the multi-hop link is using a DAF protocol the receiver can only see the channel quality of the last hop. It is assumed that the relay sends some additional information about the quality of the unseen hops to the destination, so the SNR of the multi-hop link can be estimated. The channel quality for every single block is sufficient in contrast to the SNRC, which needs exact information of the channel quality for every single block, this is a surprising result. It means that the transferred signal in an AAF system contains some information that allows correcting a small difference in the channel quality.

The performance of the combining methods, which have precise information about every single block, is just about one decibel better in SNR which has just average knowledge of the channel quality. Hence using the AAF protocol, there is no point in wasting a lot of computing power and bandwidth to get exact channel information.

General equation of SNR combining method

$$Y_D(n) = \sum_{i=1}^{k} SNR_i \, Y_{i,D}(n) \quad (12)$$

Equation representing the SNR combining method for using one relay

$$Y_D(n) = SNR_{S,D} Y_{S,D}(n) + SNR_{S,R,D} Y_{R,D}(n) \quad (13)$$

Using AAF method the signal received by the destination from the relay is given by

$$Y_{R,D}(n) = h_{R,D} X_R + Z_{R,D}$$

$$Y_{R,D}(n) = h_{R,D} \beta\left(h_{S,R} X_S + Z_{S,R}\right) + Z_{R,D} \quad (14)$$

The received signal power is given by

$$E\left[\left|Y_{R,D}\right|^2\right] = \beta^2 \left|h_{R,D}\right|^2 \left(\left|h_{s,R}\right|^2 \varepsilon + 2\sigma_{S,R}^2\right) + 2\sigma_{R,D}^2 \quad (15)$$

The signal to noise ratio is given by

$$SNR = \frac{\beta^2 \left|h_{R,D}\right|^2 \left|h_{s,R}\right|^2 \varepsilon}{\beta^2 \left|h_{R,D}\right|^2 2\sigma_{S,R}^2 + 2\sigma_{R,D}^2} \quad (16)$$

To calculate the SNR of a multi-hop link using DAF, the BER of the link is calculated which can then be translated to an equivalent SNR. The BER over a one relay multi-hop link can then be calculated as

$$BER_{S,R,D} = BER_{S,R}\left(1 - BER_{R,D}\right) + \left(1 - BER_{S,R}\right) BER_{R,D} \quad (17)$$

For a BPSK modulated and Rayleigh faded signal SNR will be

$$SNR = \frac{1}{2}\left[Q^{-1}(BER)\right]^2 \quad (18)$$

Where Q(.) is the error function.

5.2 Enhanced Signal to Noise Ratio Combining(ESNRC):

Another plausible combining method is to ignore anincoming signal when the data from the other incoming channels have a much better quality. If the channels have more or less the same channel quality the incoming signals are rationed equally.The received signal usingESNRC method can be expressed as

$$Y_D(n) = \begin{cases} Y_{S,D}(n) & , SNR_{S,D}/SNR_{S,R,D} > 10 \\ Y_{S,D}(n) + Y_{S,R,D}(n), & 0.1 \le SNR_{S,D}/SNR_{S,R,D} \le 10 \\ Y_{S,R,D}(n) & , SNR_{S,D}/SNR_{S,R,D} < 0.1 \end{cases}$$

Using this combining method, the receiver does not have to know thechannel characteristic exactly. An approximation of the channel qualityis enough to combine the signals.

6. PERFORMANCE EVALUATION

It is assumed that the three stations (sender, relay anddestination) have an equal distance from each other and therefore the samepath loss and average signal-to-noise ratio is assumed. With this equidistantarrangementSNRC, ESNRCcombining methods and AAF, DAF relaying types are compared tosee their advantages and disadvantages.The performance of different combinations of these methodsis illustrated in Table 1.

Table 1: Comparison of Performance of BER to the SNR for direct link and cooperative communication using SNRC, ESNRC combining and AAF, DAF relaying methods

SNR (dB)	PROBABILITY OF ERROR				
	DIRECT LINK	SNRC COMBINING		ESNRC COMBINING	
		AAF	DAF	AAF	DAF
-10	0.2963	0.2863	**0.2546**	0.2885	**0.2524**
-7.5	0.2444	0.2260	**0.1925**	0.2275	**0.1883**
-5	0.1884	0.1621	**0.1297**	0.1638	**0.1262**
-2.5	0.1355	0.1025	**0.0764**	0.1034	**0.0741**
0	0.0920	0.0559	**0.0391**	0.0563	**0.0378**
2.5	0.0587	0.0262	**0.0180**	0.266	**0.0173**
5	0.0353	0.0108	**0.0076**	0.109	**0.0072**
7.5	0.0208	0.0041	**0.0031**	0.0041	**0.0029**
10	0.0121	0.0015	**0.0012**	0.0015	**0.0011**

Table 1 shows the bit error rate of the direct link and cooperative communication with respect to SNR when transmitting an image through a channel having Rayleigh fading and Gaussian noise. It can be seen that DAF relaying protocol has better BER performance over AAF relaying protocol for both SNRC and ESNRC combining techniques. When AAF protocol is used SNRC technique can be adopted rather than ESNRC. For the relay using DAF protocol ESNRC method has better performance than SNRC.

The original image which is transmitted by the source is shown in Fig 4.The degraded image due to Rayleigh fading in the single link transmission channel is shown in Fig 5. This degraded image is seem to be having salt and pepper noise due to the path loss, multipath fading and noise present in the channel. It has poor quality. The images received by the receiver using different combining methods and which are relayed by AAF and DAF protocols are shown in Fig 6to Fig 9.

Fig4: Original Transmitted Image

Fig5: Faded Image received by the receiver in Direct Link Transmission

Fig6: Image received by the receiver using SNRC combining and the relay using AAF protocol

Fig7: Image received by the receiver using SNRC combining and the relay using DAF protocol

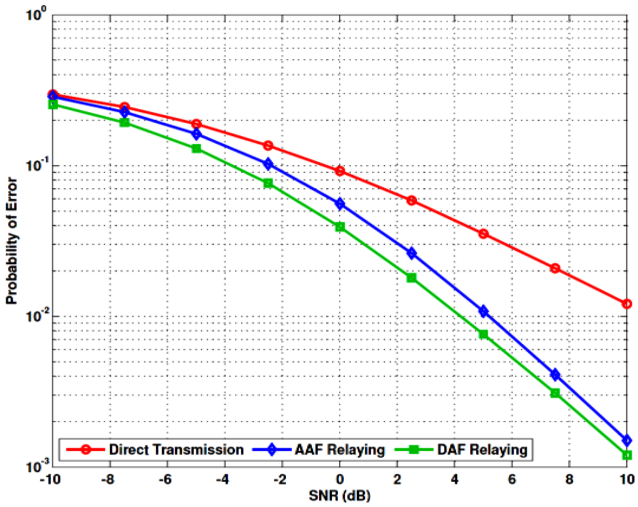

Fig 10: The BER performance curve with respect to SNR for direct link and Cooperative communication using SNRC

Fig8: Image received by the receiver using ESNRC combining and the relay using AAF protocol

Fig9:Image received by the receiver using ESNRC combining and the relay using DAF protocol

Fig 10 & Fig 11 shows the performance curves that relate Signal to Noise ratio to Probability of error corresponding to the data shown in Table 1. From the graph shown in Fig 10, it can be noted that for the small values of SNR the cooperative transmission of images is closely approximated to the direct link transmission.But for improved SNR the probability of error in cooperative communication is very much less than that of direct link transmission.In Fig 10 and Fig 11, the AAF relaying protocol shows better performance than the direct transmission and the DAF technique has low probability of error than AAF.

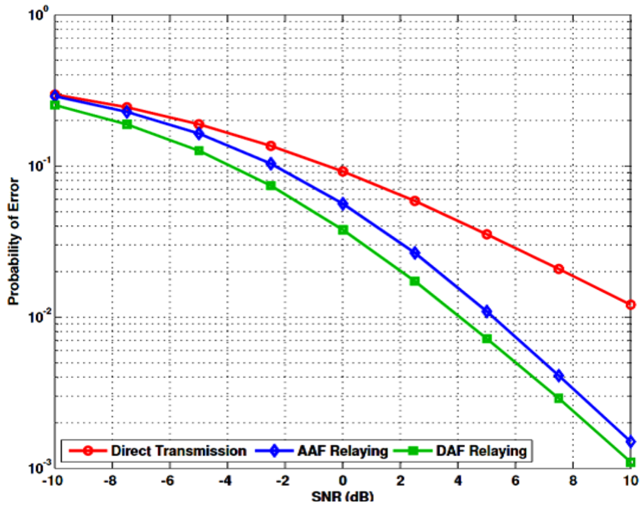

Fig 11: The BER performance curve with respect to SNR for direct link and Cooperative communication using ESNRC

7. CONCLUSION

This paper has shown the possible benefits of multimedia transmission through 3G wireless network using cooperative diversity to increase the performance. The diversity is realized by building an ad-hoc network using a third station as a relay. The data is sent directly from the source (base) to the destination (mobile) or via the relay (another base or mobile) station.

The DAF protocol has shown a better performance than the

AAF protocol whatever combining method was used at the receiver. The choice of combining method has a big effect on the error rate at the receiver. When AAF is used at the relay station Signal to Noise Ratio combining shows some benefits compared to the ESNRC technique. If AAF relaying protocol is used to meet the requirement of limited computing time, power and time delay SNRC method can be used.The Enhanced Signal-to-Noise Ratio combining has shown a very good performancewhen comparing the DAF and AAF protocols. Thus the multimedia component that can be transmitted in 3G wireless networks using cooperative diversity technique is less affected by fading and noise caused by the direct transmission.

8. FUTURE ENHANCEMENT

The current arrangement can be enhanced to get more detailed results.Another approach would be to enhance the diversity protocol with some feedback in combination with the error correcting code as described above.Digital Image Processing techniques can be adopted with the relaying protocols to improve BER performance.

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