Hybrid Information System

Matthias Siebert[1], Matthias Lott[2], Marc Schinnenburg[1], Stephan Goebbels[1]

[1]Chair of Communication Networks, Kopernikusstrasse 16, 52074 Aachen, Germany
[2]Siemens AG, Information and Communication Mobile, Gustav-Heinemann-Ring 115, 81730 Munich, Germany
E-Mail: [1]{mst|sgs|msg}@comnets.rwth-aachen.de, [2]matthias.lott@siemens.com

Abstract— **This paper introduces a new concept for intersystem cooperation of heterogeneous networks. The basic idea, referred to as *Hybrid Information System* (HIS), adopts a symbiotic approach in which measurements that are inherently available for each system are made available to heterogeneous systems as well. Thereby, mobiles benefit from other mobiles' measurements provided via the HIS on the one hand, e.g. for preparation of handover, and conversely serve as measuring entity for feeding the HIS on the other hand. The presented approach does not only allow for a minimization of self-driven scanning but also allows for further improvement of existing overall network installations or even the feasibility of future location based services.**

Keywords: Hybrid Information System, System Integration, (Vertical) Handover, Information Exchange

I. INTRODUCTION

Future radio systems will comprise 3G cellular networks like UMTS and Wireless Local Area Networks (WLANs) like ETSI HiperLAN/2 or IEEE 802.11. To exploit the complementary character of both systems, a proper interworking has to be guaranteed. Especially layer 3 inherent management and control mechanisms like radio resource management and mobility management comprise a high potential of intersystem integration. A vital service supported by these entities is handover of ongoing connections to other serving stations, e.g. Access Point in WLAN terminology and Node B for UMTS. The switching to another station of the same system is usually referred to as horizontal handover (HHO), while the vertical handover (VHO) denotes a switching between different system types, e.g. UMTS and WLAN.

An exemplary VHO scenario is shown in Figure 1, where a mobile terminal (MT, respectively 'UE' in UMTS terminology) can switch from the Node B of UMTS to the Access Point (AP) of a WLAN system. A horizontal handover (HHO) will take place if an MT (called 'station' in 802.11 terminology) changes the serving station within the same system. Important issues to be addressed when looking at VHO comprise protocol and architectural procedures, provision of system information, QoS signaling or scanning procedures.
Since VHO is an essential enabling scheme towards a fully integrated future system this paper deals with requirements for interworking of heterogeneous systems, whereby vertical handover plays an important role. The proposed *Hybrid Information System* thereby may act as an enabling technology.

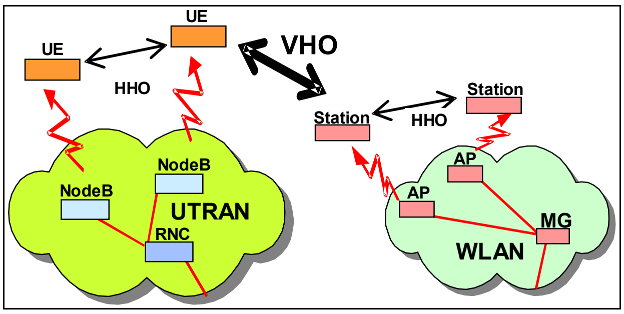

Figure 1: VHO in a heterogeneous system environment

The subsequent Section II addresses the problem of information gathering in a heterogeneous system environment. Section III introduces the HIS concept explaining the HIS elements, feeding procedure, data administration and data supply. Section IV gives further exploitation possibilities of HIS data followed by a summary and conclusion in Section V.

II. STATE OF THE ART INFORMATION GATHERING

For proper handover decision, the mobile needs to have detailed information about existence of and interference condition in a complementary system. For this, respective scanning procedures seem to be necessary. For example, if interworking between different kind of systems like UMTS and WLAN shall be facilitated, each system firstly needs to be able to detect and survey other networks.

Scanning UMTS when registered in WLAN is supported by the inherent Time Division Duplex (TDD) component and separation of users in the time domain. E.g., in the HiperLAN/2 standard the absence procedure is defined to allow a terminal to perform measurements. Similar mechanisms can be deployed in UMTS supporting the TDD mode. However, UMTS supports a Frequency Division Duplex (FDD) mode, too. In the latter case terminals in normal operation have no time to scan another system since they are required to continuously receive and transmit. To support measurements in another system in the FDD-mode, the Compressed Mode (CM) [1][2] is employed. Thereby, the same information bit rate as in normal operation is transmitted, but the actual transmission occurs only during a fraction of the radio frame. By compressing the data stream during a few slots, an idle period of up to 7 slots within one frame can be achieved for the necessary intersystem measurements [3]. Three compress-methods are defined: First, the puncturing of bits in the transport channel, second the scheduling by higher layers, and third the reduction of the spreading factor in combination with an increase of the transmit power. The latter holds responsible for the fact that application of CM inherits a number of drawbacks like increased interference, decreased cell sizes and others [4] and thus is not a preferable means to gather information. Additional disadvantages of scanning based detection of complementary systems possibly include the temporary need for interruption of current system service, increased power consumption due to frequent scanning periods and/or long periods of inactivity (neither T_x/R_x in the old system nor scanning in the target system) due to insufficient transceiver switching times.
Therefore, to avoid the above mentioned drawbacks introduced by self-driven scanning of heterogeneous systems, alternative solutions of information gathering need to be found. Within this paper, a new concept, referred to as *Hybrid Information System*, is presented whose novel approach lies in the exploitation of foreign party based measurements.

III. HYBRID INFORMATION SYSTEM

Within the previous section it was pointed out that the autonomous gathering of information by means of scanning may impact both, the own but also other transmissions. Therefore it makes sense to look for alternative ways of gaining respective measurement results. Since the need for own measurements shall be reduced as much as possible, another way of gathering the relevant information is to employ measurement reports, which have been collected by other active MTs, within the same or within other systems. Information gathering within the same system thereby is required for HHO preparation, whereas for VHO information gathering between different types of systems is needed. However, information may also be used to control other mechanism such as appropriate PhyMode selection for Link Adaptation (LA) or (joint) Radio Resource Management (RRM). In all cases, the HIS approach offers a great economic potential since participating devices can minimize or even avoid self-driven scanning procedures. The principle of the HIS presumes that each system collects data about the current link state within the covered cell and provides this information on request to mobiles that are willing to change their connection within the same system (HHO) or different systems (VHO).

Some information is already provided by broadcast channels but they usually do not include information about neighboring or different systems. Nonetheless, even if the existence of other systems was announced in the broadcast channel, the question remains which link conditions a station can expect if it really changes to the announced system. Thus, the new topic is that information about other systems *as well as* their link conditions needs to be provided. Especially, for the VHO-case this means a remarkable gain. To avoid misunderstandings: It is not explicitly proposed to include vertical system information in current broadcast transmissions. In fact, the underlying concept of employing measurements taken by other parties shall be promoted. The way *how* this information is provided, respectively whether this information needs to be provided to the terminal at all (in case of network based control mechanisms) is further addressed in Section D. Anyway, the interesting aspect concerning the gathering of those measurement reports is that they do not need to be rendered explicitly. Such, the Hybrid Information System proposes to exploit information being available anyway, e.g. signaling information with the original purpose to adjust power control mechanisms or link adaptation. The challenging task thereby is *how* the information needs to be processed, recycled and supplied.

A. GENERAL OVERVIEW

The basic idea behind the HIS approach is illustrated in Figure 2. Each system reports about the current state, i.e. the link condition including, e.g., interference distribution. Together with a measurement report the location of the reporting mobile within the covered cell is registered, see (1). The data is stored in a data base (2) such that mobiles of another system willing to change may request this information. Depending on the new target system, the mobile is supplied with state reports of the same system type (for horizontal handover, HHO) or a vertical system (vertical handover, VHO), cf. (3,4,5), and subsequently may perform the (V)HO, see (6).

Feeding and Information Clients

While Figure 2 gives a short overview on the basic principle of the proposed HIS scheme, Figure 3 explains in more detail the involved entities and their interaction. On the left side of the picture one can see the so called *Feeding Clients* of System A and B as well as the respective *Information Clients*.

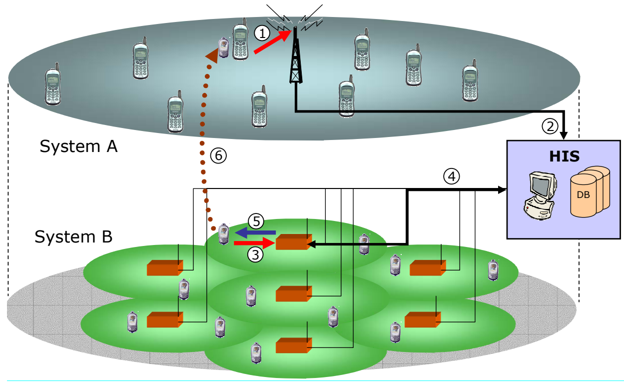

Figure 2: HO information data: Gathering and exchange between different systems

The vertical separation here between those clients indicates their logical separation and is not related to the actual geographic position during operation. Feeding clients are inherently all mobiles that transmit measurement reports to the fixed network. Depending on the level of integration into the HIS, mobiles may act as feeding client without even being aware of this task. E.g., terminals sending information about power control implicitly provide information on the link conditions. Information clients are terminals that somehow make use of the information as provided by HIS. It is worth mentioning that HIS is not restricted to the control of heterogeneous systems, but may also be applied for the performance enhancement of homogeneous systems. If the information is used e.g. to support HHO only system internal information is used, which means information client A uses information gathered by feeding client A beforehand. Nonetheless, the actual signaling flow is realized via the HIS, which due to its definition is the logical connection point for both, horizontal and vertical information exchange.

Localization Units

The basic property of HIS is to map incoming measurement reports to specific locations. Therefore it is of existential importance to support location of the feeding clients. In principle two localization alternatives are possible: Either feeding clients perform self-localization, indicated by the two *Self Localization* boxes on the left side of Figure 3, or the HIS system acquires the feeding clients' position by *Foreign Localization*, indicated by the respective box in the HIS.

Intelligent Service Control and Data Base Units

Central elements of the Hybrid Information System are the *Intelligent Service Control* (ISC) unit and an affiliated *Data Base* (DB). The task of the ISC is to administer incoming data from the feeding clients and to respond adequately to information requests from the information clients. Depending on the purpose for which data shall be used, the ISC may also perform respective filtering and averaging – this applies to both time and space domain. Depending on the level of sophistication of the overall HIS, the ISC may not only take over passive and reactive operations like the respond to explicit information requests but also active jobs. As an example, the ISC could monitor and track movements of a respective station of system A and spontaneously inform it as soon as it enters the coverage area of another (vertical) radio system B with better radio conditions or properties. Due to the well founded and-up-to-date HIS information a new quality of the Always Best Connected (ABC) paradigm could be reached.

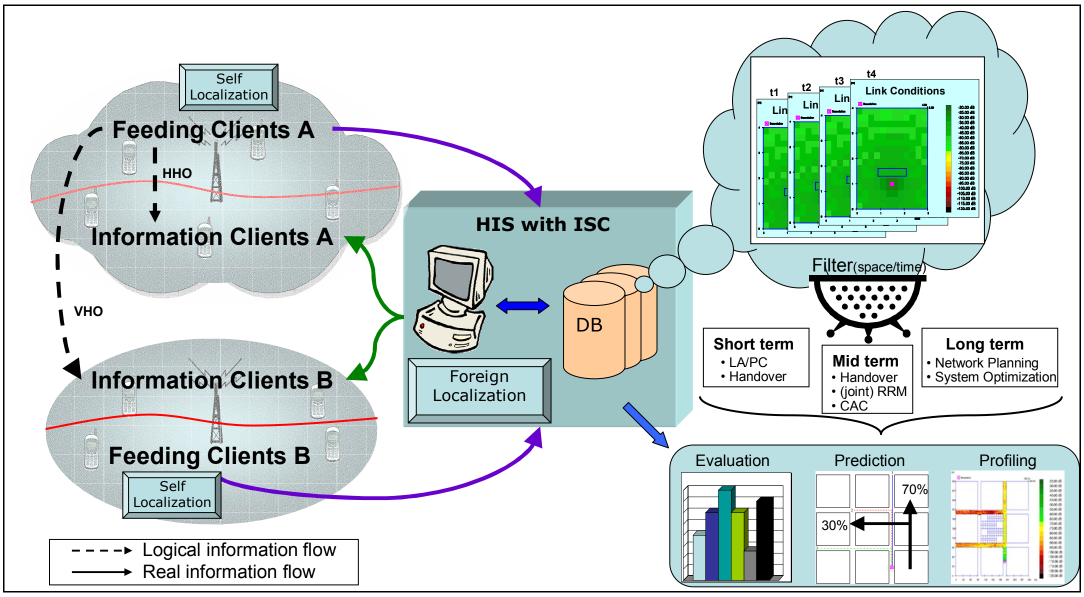

Figure 3: Feeding, administration and supply of data within the Hybrid Information System

B. FEEDING OF THE HYBRID INFORMATION SYSTEM

The HIS administers databases reflecting the current link conditions, e.g., interference situation, in each of its associated subsystems, see Figure 3. Assuming that localization predominantly takes place by the network (foreign localization), in principle there is no additional signaling between the mobiles (feeding clients) and the BS/AP is necessary for the feeding of the HIS databases. The respective information should be available at the base station anyway, e.g. in the context of power control, link adaptation related signaling, number of automatic repeat requests.

Measurements in UMTS

In UMTS three kinds of handover are standardized: the horizontal (cell to cell), the intra-system (e.g. TDD to FDD) and the inter-RAT (e.g. UMTS to GSM) handover. This leads to different measurement classes. The intra frequency measurement is employed in the case of horizontal handover to monitor the Primary Common Pilot Channel (CPICH) in FDD and the Primary Common Control Physical Channel (P-CCPCH) in TDD mode of the own cell and the neighboring cells. Parameters for measurements may be the Received Signal Code Power (RSCP) and Ec/N0, where E_c denotes to the received energy per chip and N0 to the power spectral density in the band. To qualify the performance of the current link estimations on the block error rate (BLER) are evaluated, too.

The inter frequency measurements survey the surrounding cells on different frequencies (other carriers) to find a possible target for a handover. The measurement values are similar to intra-frequency measurement values.

The inter-RAT measurements are provided for the inter-RAT handover which is only standardized for GSM-UMTS/UMTS-GSM handover yet.

Measurements in GSM

Like in UMTS, the MT must monitor surrounding cells and other mobile radio networks to perform a handover if necessary. Hence, the own link quality should be compared with the signal strength of the possible destination. The intra-frequency measurements consist of received level (RXLEV) and the received quality (RXQUAL) of the serving base station. They are taken of each associated Traffic Channel (TCH).For the HO to an adjacent cell the RXLEV of the Broadcast Control Channel (BCCH) of up to 6 neighbors is monitored. The inter-RAT handover from GSM to another RAT is so far only planned for UMTS TDD and FDD.

Measurements in 802.11

In the IEEE standard 802.11 [5] for Wireless Local Area Networks (WLAN) the use of measurement reports for information exchange between Access Point (AP) and Station (STA) is not standardized. But supplement 802.11h introduces some basic measurement and reporting structures. Nevertheless, this supplement does not define any inter-RAT measurement procedures. Hence, there is no standardized way of performing a handover from WLAN to other cellular mobile radio networks.

For intra-system monitoring three different measurement reports are available. The Transmit Power Control (TPC) contains the current transmitted power for an effective power control, the Received Power Indicator (RPI) measures the received power level for a specified duration of time and the Clear Channel Assessment (CCA) determines the current state of use of the wireless medium.

For all the above mentioned measurement procedures Table 1 depicts these procedures for UMTS, GSM, and IEEE 802.11 together with respective reporting periods.

C. HIS INTERNAL DATA ADMINISTRATION

To allow for a reliable and smooth operation of the HIS, incoming data from the feeding clients needs to be administered and stored. For this, a set of *Data Base* servers is associated to the ISC in the HIS, see Figure 3. Their task is the reliable and fast storage and access to dedicated system information. Basic entries in the DB comprise a compound of measurement reports, positioning data and time stamp. By such, an internal representation of the link/interference condition within each associated radio system, a so called *link map*, is achieved.

Table 1: Measurement reports and periods

	Intra-frequency	Inter-frequency	InterRAT
UMTS	CPICH: RSCP *Ec*/*N0* P-CCPCH: RSCP, *Ec*/*N0* Period: 200ms Measurements like BLER: Up to every 250 ms	CPICH: RSCP *Ec*/*N0* P_CCPCH: RSCP, *Ec*/*N0* Period: 480ms	GSM RSSI Period: 480ms
	TS 25.331 Cha. 10.3.7 & Cha. 8.4 [6]; TS 25.133 Cha. 10; [7]; TS 125.302 [8]		
GSM	RXLEV and RXQUAL of the Associated TCH Period: 480ms	RXLEV of the BCCH-carrier of adjacent cells Period: 480ms	CPICH: RSCP *Ec*/*N0* P-CCPCH: RSCP, *Ec*/*N0* Period: 480ms
	TS 100.911 Cha. 8.4 [9]		
802.11h	Transmit Power Control Received Power Indicator Clear Channel Assessment Period: on demand		Not specified
	802.11h [10]		

With the reception of new measurement reports, an update of the link map is triggered. By such, the link map has a different set up at respective points of time (t_1, t_2, t_3, t_4, …) as indicated in Figure 3, resembling 'salami' slices. The minimal thickness of those slides thereby is directly related to the interarrival times of the measurement reports of the feeding clients. Thicker slices result from quantization of measurement reports whereby a diversified weighting of probes within one quantization interval by the ISC is possible. Besides a time concerned description of the DB maintained data, the 'salami' image matches well in another sense: The granularity of the slices in the salami metaphor corresponds well to the spatial resolution with which the HIS may provide interference information. The spatial resolution again is directly related to the penetration and position of feeding clients within a given system.

Besides the *basic entries* in the DB, further parameters could be added. *Extended entries* consist of terminal related properties such as velocity, moving direction, current service consumption and others. Such, the extended entries support personalized service provision. By evaluation of those data it is possible to set up user profiles. Additionally, it will be possible to predict user requirements. If for example a user moves with high speed along a road, it is very unlikely that he will spontaneously turn left or right. Such, an enhanced RRM mechanism could exploit the HIS information to prepare a planned handover to another serving BS/AP in the near future. Due to the interference maps, the current link condition in the future target system is well known, such it can be decided whether extra bandwidth needs to be reserved for the shortly to handover terminal. Moreover, if the geographic target is covered by several vertical systems, the HIS may even trigger intersystem support for the terminal and support joint RRM in this way.

An interesting point with respect to usability of the information stored by HIS is the task, for which respective data shall be applied. Obviously it makes not much sense if a mobile that wants to handover to another (vertical) system is provided with interference information being totally out-of–date. On the other hand, if system engineers want to get more information on areas with low coverage, neers want to get more information on areas with low coverage, they are not interested in present fading analyses. The concept of HIS accommodates both needs by distinguishing between short term, mid term and long term data, see Figure 3. Short term data is meant to support real time requests from the information clients. As soon as a feeding client provides new measurement reports, the essence is extracted and stored in the HIS DB. By such, short term data reflects the latest entries in the data base. Respective information is used to serve as decision basis for close-by handover decisions, LA/PC support and the like. Mid-term data instead is less time critical. It is based on short-term input but due to respective filtering and averaging time selective fading effects are equalized. Nonetheless, mid-term data is of interest for ongoing communication since it serves as set value especially for *predictable* actions. Especially in combination with prediction and profiling (see Figure 3) mid-term data is useful for planned handover triggering, (joint) RRM or Connection Admission Control (CAC). Finally HIS distinguishes long-term data. This can address either permanent impacts, e.g. to determine areas with ongoing insufficient link quality or recurrent events such as the analysis support of daily occurring networking congestions during e.g. rush hours.

The logical separation in short-, mid- and long term data is directly related to the complexity of the DB hardware. For the different types of data, three different DB units are foreseen respectively, see Figure 3. Due to the high challenges with respect to Time To Respond (TTR) and memory, DB servers handling short term data are expected to be much more complex than respective long-term DB server. Besides the mentioned separation and filtering of data in the time domain, additional filtering algorithms in the space domain will become necessary, e.g. if information is requested for positions for which no entry exists in the DB. A possible solution would be to rely on entries for positions having minimum Euclidean distance. However, this topic is subject of further study.

Self healing property

An assumed drawback of the HIS concept is that the loading of the HIS DBs depends on the number and position of the feeding clients. If namely only few feeding clients provide measurement reports, this has a direct impact on both, the spatial resolution (granularity of 'salami' slices) and the time resolution (thickness of 'salami' slices) of the maintained interference maps. However, concerning the long-term data this of minor influence. The only difference is that the timeframe for the collection of data needs to be extended such that sufficient probes/measurements reports can be evaluated with statistical reliability. Concerning the mid- and short-term data whose intention is to support and influence live decisions, a high number and timeliness of measurements form feeding client seems to be inevitable. Nonetheless, recalling the original intention of information requests by the clients opens up the self healing property of the HIS concept: Either, the target system is highly penetrated with feeding clients. This results in a proper and up-to-date interference map of the target system/area. Such a mobile willing to handover gets a pretty precise image of the target system and may estimate based on this input whether a handover is worthwhile or not. Or, only few feeding clients are currently served in the target system. In that case, the HIS interference maps are quite imprecise. However, the impreciseness itself has a negligible impact since this is a good indicator to the mobile that the target system is not busy at all. Such, only little interference is to be expected after handover. In such a way, HIS information is helpful for both cases, high and low penetration (self-healing property of HIS).

D. HIS DATA SUPPLY

In general, two controlling schemes are possible: First, decisions such as handover control are network based and second, decisions are mobile based. This also corresponds to the way HIS is involved in information provisioning: HIS may either ‘work on request’ meaning that information is only provided after an explicit request has reached the ISC (in mobile controlled scenarios) or HIS may play a more active part and provide information autonomously to the terminals (network controlled scenario). Even the realization of push services based on HIS information is thinkable.

The one open question is still how the data transfer from the HIS databases to the mobiles shall be realized? While the feeding of the HIS can be assumed to proceed without additional traffic, the information provision needs explicit signaling. Obviously this is only necessary, if the mobile is in control. Network based scenarios do not need to perform signaling to allow terminal to take decisions. Anyway, if information needs to be signaled to the terminals, basically there are different options: One is to use resources of the current system the MT is connected to. For this, existing broadcast channels could be enhanced to also transmit neighboring-cell and foreign system related data. Obviously, the introduced overhead is a clear disadvantage of the enhanced broadcast solution. Therefore, the requested information could be transmitted in an in-band fashion, piggybacked with other data the MT is exchanging with its actual base station. In such a way, only the MT that is willing to change receives the necessary data. However, this approach is only possible for planned HO, where there is enough time to provide the data on the old link. On a sudden deterioration of the link quality, the mobile still can fall back to scanning solutions. Nevertheless, with the new approach a scanning of neighboring systems is not needed for a planned HO and the disadvantages inherited with, e.g. the compressed mode, can be avoided. Even more, in case of a network controlled HO no signaling between the MT and BS is required since all necessary information are available at the BS. Besides a continuous connection to the BS/AP in the serving system, the new approach also reduces power consumption; respectively increases standby time because power consuming measurements on other frequencies/systems are obsolete.

IV. FURTHER EXPLOITATION OF HIS DATA

Once the HIS DB is set up, benefits do not only restrict to ongoing communication. Especially long-term data hold a high potential for further optimization tasks. In combination with profiling, personalization and prediction, conventional services are to be improved and new applications can be invented. Areas in which data gained by HIS are:

- Location based services
- Scanning of private areas
- Network optimization
- ABC support
- Coverage optimization
- Support of planned actions
  - Handover
  - RRM

Projects like CELLO [11] utilize the mobile location information for various enhancements of the 2G/3G mobile networks.

V. SUMMARY AND CONCLUSION

Within this paper abstract, a new concept for intersystem cooperation, called Hybrid Information System (HIS), was introduced. For the symbiotic concept, mobiles (feeding clients) provide system information to be evaluated and stored by the HIS on the one hand, and benefit (information clients) from other mobiles’ measurements provided via the HIS on the other hand, e.g. for preparation of handover. It is to note that the physical location of both terminals, the measuring and the beneficial one, need to be approximately the same. However, even for mobiles having only approximately the same positions it can be assumed that the interference level and long-term propagation conditions at both locations are correlated. Besides this,

However, HIS offers a further high potential to be exploited: Once a detailed link budget map of different systems is available further improvement of existing installations and services is possible, e.g. improved network planning based on evaluation of reports with increased number of dropped calls in certain areas. Additionally, if an operator runs heterogeneous network installations, load balancing by strategic handover order is possible. Additionally, HIS may act as enabling system to support or even facilitate future services: The exact knowledge of position and related link budget allows the realization of value added location based services considering the always best connected dogma.

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