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The measurements and comparisons of media networks

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Abstract: The quantitative measurements of the essential properties and information communication abilities of physical media and media networks are proposed in this paper. Such as the number of sub-networks, the number of lecturing sessions, the number of accepted copies, information power factor and interaction ability et al. The measurement results for media networks of broadcasting, Client/Server, phone-like, single-producer peer-to-peer and multi-producer peer-to-peer types are derived respectively. They are the scientific foundation for understanding, analysis, comparison, monitoring, management, evaluation and utilization of media networks.

Keywords: Media networks, interaction ability， information power factor， accepted copies， number of lecturing sessions，number of sub-networks

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A number of scholars including Marshall McLuhan have provided qualitative descriptions on “physical medium” and “communication” in communication and sociology theories(Jing X, 2007) (Qingguang X,2008) (Fan S and Hailong Q ,2007). However, the lack of formal quantitative descriptions for measurement criteria is a great hindrance to analysis, comparison and utilization of media networks. In fact, the development of science and technology always accompany and impel the development of physical medium, mass media and media networks. Thus， it is highly necessary to analyze, recognize and describe the essential properties and information transmission abilities of all kinds of media networks, and construct a number of quantitative indicators for measurement criteria, in order to provide the scientific foundation of analysis, comparison, monitoring, management, evaluation and utilization for media networks.

1. Physical Medium, Mass Media and Media Networks

Physical medium is the physical carrier of information between the senders and the receivers (Jing X., 2007) (Qingguang X., 2008). It has three essential physical properties: information deposit (or modulation, storage), information transmission, and the deposited time is no less than the time spent on the information transmission to the receivers.

“Transmission” is substantially comprised of two basic ordered operations. The information is firstly deposited to the medium, and then accepted by the receivers through relative move (or transmission) across space. There are three types of the relative move. The most common type is that physical medium is moving while the receiver remains stationary. The physical medium is activated by certain energy to produce vibration, fluctuation or movement to transmit the deposited information from the sender to the receiver in different space, such as the primitively-fluctuate physical media (like the light, electricity, air and water) which have the capabilities of storage and transmission simultaneously. Apparently, this kind of relative move will cost some time, which is the time delay. The other type is rare which is that the physical medium remains stationary while the receiver is moving. For example, the flowers put on the window-ledge by the agent, artifacts in vaults and rock-paintings in caves; they are static physical media in which the storage is separated from transmission (ignoring the final step of human eyes getting information by the light). The last type is that both the physical medium and the receiver are moving, just like the moving cell phone during a call. (The relative moves within a short distance can be categorized to the first type.)

"End Entity" is a man, computer, sensor, robot, or equivalent intelligent agent et al. It has three types: the one who only produce information, the one who only consume information and the one who can produce and consume information. The end entity is called "producer", "consumer" or "prosumer" respectively according to its type. And for multi end entities, they can be called "producers", "consumers" or "prosumers" respectively. The "producer" or "producers" produce and publish information, such as actors, players, lecturers, authors, publishers, issuers, podcasters, bloggers or micro-bloggers et al. The "consumer" or "consumers" consume information, such as spectators, listeners, readers, browsers or experiences et al. The "prosumer" or "prosumers" which produce and consume information simultaneously has double identities, such as bloggers, micro-bloggers, QQ users, or social network members et al.

"Mass media" is a one-way open-loop system which can produce, issue and disseminate information. It is composed of producers and physical media. Producers are the source of information, usually are organization composed of human beings, or websites, CDN (Content Delivery Network) et al. Physical media are the carrier for information communication. Producers and Physical media compose traditional media (or mass media, media in a narrow sense) which only issue one-way information and assume that the information is correctly accepted by the consumers in general. Mass media do not consider the consumers, unless the information feedback is carried out particularly. Mass media cannot get the consumers' information directly and duly.

"Media networks" is a two-way closed-loop system which can produce, issue, propagate, accept and feedback information. It is composed of mass media and prosumers. The "closed-loop" includes the forward physical medium channel from producers to consumers and the inverse backward physical medium channel from consumers to producers. Thus, the producers and consumers can communicate with each other. In this way, not only the producers can get the consumers' states timely, (including whether the information is received correctly and the reaction of consumers) but also the consumers can produce and publish information as producers. The inverse backward information communication is exactly the missing property of traditional media.

"Media networks" is defined as the set of end entities and physical media. That is $N_{media} = \{T, M\}, |T| = n,$ where $n \geq 2$ and T is the set of n end entities. Each member of T can be producer, consumer or prosumer. There are at least one producer and one consumer in T. M is the physical media which connect the members of T. Media networks can be called as "M-nets" for short.

Existing m-nets can be grouped into five typical types according to the status and relationships between the producer and consumer, such as the interaction ability and the peer (or non-peer) relationship between them. They are:①broadcasting type, such as broadcasting, radios, televisions and films et al; ②Client/Server type, such as newspapers, bookstores, websites and data center et al; ③ phone-like type, such as fixed telephone and cell-phone et al; ④single-producer peer-to-peer type, such as BT, Thunder and PPlive et al;⑤multi-producer peer-to-peer type, such as twitter, face-book and renren.com et al.

2. Fundamental Measurements of Media Networks

In order to give a formal description of M-nets and its communication ability, we first define some independent properties and then extend them to get some convenient comprehensive measurement indicators.

- M-nets Diameter *d*: the maximum distance between all of the producers and consumers. The unit of M-nets diameter is kilometers (km). $d = \max\{d_{ij} \mid i \neq j\}$, where d_{ij} is the distance between the end entities *i* and *j* in M-nets. The arithmetic mean value of all the distances between the end entities can also be exploited as the M-nets diameter, that is $d = \frac{2}{n(n-1)} \sum_{i \neq j}^{n} \sum_{j=1}^{n} d_{ij}, (n \geq 2)$. d_{ij} can also be briefly expressed by the hop counts or the number of links between *i* and *j*.
- M-nets Time Delay *t*: the average time spent on the first bit transmission from producer to consumer. M-nets time delay is the sum of processing time (including queuing and transformation et al.), sending time and traveling time of all transmission steps. Not only the total time delay has several order of magnitudes differences, but also the proportions of time delay form different parts are quite different for different kinds of M-nets. For the M-nets with separated storage from transmission (such as bamboo slips, books, mobile hard disk and USB flash disk et al), the traveling time delay of the physical media is the major part of the total delay, maybe several hours, a couple of days or even several months. The processing and sending time delay can be relatively negligible. On the contrary, for the digital optoelectronic M-nets, especially the existing high-speed Internet, the traveling time delay can be negligible, the processing and sending time delay is the major part, usually is several milliseconds (10^{-3} seconds). In fact, the time delay for each travel is affected by the congestion status on the channel, and fluctuates around the average value. Besides, we assume *t* as the forward delay and the time cost by the travel from the consumer to the producer is called backward delay expressed by t_{rev}. Many consumers of one-way physical media cannot transmit reversely, that means t_{rev} is infinite ($t_{rev}=\infty$). The sum of the forward delay and backward delay is called the round-trip delay which is twice the forward delay(2*t*) in general. The round-trip delay is an important factor in M-nets throughput rate.
- M-nets interaction ability *r*: the ratio of forward delay to backward delay in a M-nets, $r = t / t_{rev}, (0 \leq r \leq 1)$. If producers and consumers (human beings, animals or intelligent agents) of a M-nets can send information and response in nearly the same time delay, then $r \approx 1$ and the M-nets is considered to be interactive. On the contrary, if the backward delay is several order of magnitudes higher than the forward delay, or the end entities cannot even response (that is the backward delay tends to be infinite), then $r \approx 0$ and the M-nets is considered to be non-interactive. According to this definition, the telephone and Internet are considered as interactive ($r \approx 1$), while broadcasting, television and film media are considered as non-interactive ($r \approx 0$). Certainly, in meaningful applications, the forward delay and backward delay must be acceptable to the M-nets end entities. For example, the time delay for people waiting for response from each other should be less than several minutes or seconds, otherwise we can hardly consider the conversation as interactive. Based on the interaction ability, the interaction intensity can be defined as the times of effective interactions for limited information per unit time. Interaction intensity can express the frequency of information updating between producer and consumer in acceptable time delay. The higher interaction intensity is, the faster information communicates (or updates) and the more information both sides get.
- Information transmission work *w*: work done during transmitting a certain amount of information to a certain distance away. It measures the transmission ability of a M-

nets and can be called “ITW” for short with unit of kilometer-bit(kmb). ITW equals to the product of transmitted information quantity and transmission distance. It is in accord with the fact that more transmitted information and longer transmitted distance leads to stronger transmission ability of M-nets. Here, information quantity (bits) is conceptually corresponding to the mass of mechanical work. Although information is not a material and does not have any mass, in fact we need a certain amount of substances to carry and represent information. The minimum mass of substances used to represent one bit varies greatly for different physical media and technologies. For example, considering a vase of flowers appearing on the windowsill as one bit of information, it may be several kilograms, while considering a capacitor filled with electrons as one bit of information, it is about 40,000 electrons weight on average(Stephen C., 2007)(3.64×10^{-23} grams). We can refer to 40,000 electrons as current standard equivalent mass of one bit. If lighter quantum is used instead of electron in the future, it would take much less mass to represent one bit of information.

3. Size Measurement of Media Networks

If there are $n(n\geqslant2)$ end entities in a media networks N_{media}, they cannot be always online at the same time. They usually form lots of distinctive sub-networks in a large media networks based on the time, space, interest and topic et al. If n is huge enough (such as with order ten million or hundred million et al), in general, it is the sub-networks that acts frequently.

- Media subnet: subset of media networks M_i, $M_i \in N_{media}, (|M_i| = i, 2 \le i \le n)$, M_i consists of i end entities (at least one producer and one consumer) and the connected physical media. Varying numbers of media subnets are constructed according to physical properties of the physical medium, functions of end entities and rules of network deployment. The information production, dissemination and acceptance mechanisms and the structure of media subnets are relatively independent and closed.
- Number of media subnets X (or subnet’s scale): the numbers of media subnets constructed based on different network forms are different for the same media subnets with n end entities. ① for broadcasting media networks, its subnet is the same network(David S.) as itself, so X=1. ② for client/server (C/S) media networks, a server(producer) connects to other n-1 clients(consumers) respectively, so $X=n-1$.③ for traditional phone-like media networks, since each end entity could perform as a producer or a consumer separately, a minimum media subnet can be built by two different end entities(Robert M.), so $X = C_n^2 = n(n-1)/2$. ④ for peer-to-peer(P2P) media networks, every i ($2\le i\le n$) end entities can construct a media subnet(David P. R.), so $X = \sum_{i=2}^{n} C_n^i = 2^n - n - 1$. For example, considering four end entities (n=4) in the peer-to-peer media networks, there will be six dialogues(or games) between two persons, four talks(or poker games) among three persons, and one discussion(or mahjong entertainment) among four persons, the total number of media subnets is 6 +4 +1 = 2^4-4-1 = 11.
- Number of lecturing sessions in media networks Y. A so-called lecturing session is an information broadcast on media subnets. A lecturing session is composed of a producer (or the source of the original information) and a certain number of consumers. The number of lecturing sessions of a media network is the sum of the number of lecturing sessions on all subnets. The number of lecturing sessions on a subnets is equal to the number of producers on the subnets. ① for broadcasting media networks which has one subnet (itself) and only one producer, i.e. the broadcaster, so $Y=1\times1=1$. ② for client/server (C/S) media networks, there is always one server (producer) which can construct different lecturing sessions with other n-1 consumers, so $Y=1\times(n-1)$=n-1.③

for traditional phone-like media networks, the two end entities can perform as a producer separately, the number of producers is two, so $Y=2\times n(n-1)/2=n(n-1)$. ④ for single-producer peer-to-peer media networks, there is only one producer, e.g. P2P live media networks or P2P media networks on demand, so $Y=1\times(2^n-n-1)=2^n-n-1$. ⑤ for multi-producer peer-to-peer media networks, each member of a subnet can be a producer, it means that there are *i* producers on a subnet with *i* ($2\leqslant i\leqslant n$) end entities, such as micro-blog (active pushing), blog (passive searching), podcasts, social networks et al, so $Y=\sum_{i=2}^{n} i\times C_n^i = n(2^{n-1}-1)$.

- Number of accepted copies in media networks *Z*. *Z* is the number of the copies accepted by all the consumers in all lecturing sessions. That is the sum of the number of consumers in all lecturing sessions. Obviously, each consumer in a lecturing session can receive a copy from the producer. *Z* shows the total information effectively transmitted on media networks; it is an important indicator to measure the transmission ability of a M-nets. ① for broadcasting media networks, which has only one lecturing session and *n*-1 consumers, $Z=1\times(n-1)=n-1$. ② for Client/Service media networks, which has *n*-1 lecturing sessions and only one consumer in each session, $Z=(n-1)\times 1=n-1$. ③ for phone-like media networks, which has $n(n-1)$ lecturing sessions and only one consumer in each session, $Z=1\times n(n-1)=n(n-1)$. ④ for single-producer peer-to-peer media networks, a lecturing session consisting of $i(2\leq i\leq n)$ end entities has one producer and $(i-1)$ consumers, so $Z=\sum_{i=2}^{n} C_n^i(i-1)=n2^{n-1}-2^n+1$. ⑤ for multi-producer peer-to-peer media networks, each end entity can make a speech, each lecturing session consisting of $i(2\leq i\leq n)$ end entities has (i-1) consumers, so $Z=\sum_{i=2}^{n} C_n^i i(i-1)=(n^2-n)2^{n-2}$.
- Information power *P*. *P* is the power of information communication during unit time in media networks; it is a measurement of the information communication efficiency. That is $P=w/T$ with basic unit of kilometer bits per second (or kmbps) where *T* is the time spent on the successful transmission of information with transmission work *w*. Assume that the M-nets diameter is *d* and the average information quantity of each accepted copy is *a*, then $w=adZ$. Since every broadcast of a lecturing session will spend an average one-way delay *t* (or round-trip 2*t*), $T = Yt$ (or $2Yt$). Thus $P=w/T=adZ/Yt=edb$, where *b* ($b=a/t$) is the throughput rate of media networks or the bandwidth of physical media with unit of bits per second (often written as bps) and *e* ($e=Z/Y$) is the power factor. For broadcasting, Client/Service and phone-like media networks, the power factors are as followed: *n*-1, 1, 1. If *n* is huge enough, the power factors of the single-producer peer-to-peer M-nets and multi-producer peer-to-peer M-nets can be simplified to $(n-2)/2$ and $(n-1)/2$ respectively. It can be concluded that the so-called transmission power of M-nets is the product of propagation distance, bandwidth (or throughput rate) and the corresponding power factor. Information power is very useful to analyze and evaluate the transmission efficiency of M-nets.

Transmission Ability of Media Networks

The transmission ability of media networks is a measurement used to effectively describe the comprehensive effect of the producers' information producing, the physical media's information transmitting and consumers' information accepting. Apparently, larger M-nets diameter, smaller time delay, stronger interaction ability and more prosumers will produce stronger transmission ability. Thus, the M-nets diameter, time delays, information power factor, interaction ability and the number of accepted copies discussed above can be directly used to analyze and evaluate the transmission ability of M-nets.

Firstly, the physical medium's impact on the transmission ability of media networks is discussed. Physical medium is a crucial physical component of media networks; its function and performance have direct impact on the overall transmission ability of M-nets. According to the evolution of physical media utilized by human beings, the physical media can be grouped into three main categories: ① Natural light and air type, refers to the physical medium which can be directly perceived and used by human beings without transformation, such as visible light, air, water et al.②Separated storage from transmission type, refers to the physical medium via which storage and transmission are proceeded separately, such as the integrated physical media of which the characters (a form of information) are stored onto the light physical medium (such as bamboo slips, papyrus, silk, papers and USB storage devices et al) and then dispatched to the destination by transportation (such as animals, human beings, motor vehicles and vessels). ③ Artificial Optoelectronic type, refers to the light and electricity physical media which are utilized after optoelectronic transformation (especially after digitalization). This kind of physic media are the primary physical media of modern media networks, such as the radios, telephones and the optoelectronic equipments used for Internet and wireless communication.

In order to quantitatively measure and compare the transmission abilities of the three types of physical media, the measurement values of their indicators are listed out. These indicators are very convenient and useful to measure a specific medium and its propagation, but it is difficult to compare them in a unified abstract scale. The reasons are as follows: one reason is that some indicators are not independent, for example, the diameter, time delays and throughput rate are related with the end entity's performance and the transmitted information quantity; the other reason is that there are significant differences not only among the three types of physical media but also among the different specific physical media of the same type. In order to illustrate the measurement process, we give a unified measurement process for a most simple information transmission case which can be realized through the three types of physical media. Details are shown in table 1. The aim is to transmit the book "A Dream of Red Mansions" with 731,017 Chinese characters (around 1.2×10^7 bits) to the destination 100 meters away, the information power is about $w=1.2\times10^7\times0.1\text{Km}\approx1.2\times10^6$ kmbit.

Table 1 Basic measurement process of three types of physical media

Physical Media type	Diameter ***d*** (km)	Time Delay ***t*** (s)	Throughput Rate ***b*** (bps)	Temporarily Transmitting Information ***c*** (bit) ★	Information Work ***w*** (Kmbit)	Information Power ***P***(kmbps)
Natural Light and Air	$\leqslant 0.1$	1.5×10^5	80	24	1.2×10^6	0.5
Separated Storage from Transmission	$\leqslant 10^3$	6	2×10^6	1.2×10^7	1.2×10^6	2×10^5
Artificial Optoelectronic	$<\infty$	1.2×10^{-3}	10^{10}	5×10^3	1.2×10^6	10^9

★Temporarily Transmitting Information is the amount of information temporarily attached with the medium while transmitting, numerically equals to the product of the transmission delay and throughput rate of media networks.

Natural light and air physical medium. The effective listening and speaking distance between two people through air is no more than a hundred meters in an ideal environment. The send delay of reading "A Dream of Red Mansions" for peoples a hundred meters away as fast as possible (300 Chinese characters per minute) is 1.5×10^5 second(ignoring traveling delay of 0.3 second), the throughput rate is around 80 bps, temporarily transmitting information is about 24 bits and information power is around 0.5 kmbps.

Separated storage from transmission physical medium. Considering the common transportations which deliver letters, magazines and newspapers (taking horse carrying books as an example), they usually act inside a circle of 1000km radius on average. Carrying a book “A Dream of Red Mansions” on its back, a horse with a speed of 60 kilometers per hour will spend 6 seconds on covering 100 meters (assume that the send delay is 0). The throughput rate is around 2×10^6 bps, the temporarily transmitting information is 1.2×10^7 bits and the information power is around 2×10^5 kmbps.

Artificial optoelectronic physical medium. Considering the Internet with throughput rate of 10Gbps and the send delay of 1.2×10^{-3} seconds (ignoring the traveling delay of 0.5×10^{-6} second), its temporarily transmitting information is $0.5\times10^{-6}\times10^{10}=5\times10^3$bits and the information power is around 10^9 kmbps.

Though it is the measurement process of a specific transmission case that listed in table 1, the results can provide useful foundation of comparisons for different types of physical media. Apparently, the physical medium of natural light and air type has the shortest transmission distance, very low throughput rate, much small temporarily transmitting information and low information power. The reason is that the lack of modulation to the light and air brings low sending efficiency. The time delay of this type is the longest one too. The separated storage from transmission physical medium has two special advantages which are the largest temporarily transmitting information and the information non-volatility. The physical medium of artificial optoelectronic type has almost all the advantages, its information power is several order of magnitudes higher than the other ones, which means it is the most efficient.

The integrated communication ability of M-nets is discussed as follows. Table 2 lists the numerical measurement results of the number of subnets, number of lecturing sessions, number of accepted copies, power factor and interaction ability for five typical kinds of M-nets. Obviously, they can also be used to measure other kinds of M-nets or a specific M-nets for M-nets analysis, comparison and evaluation. We can just use the number of accepted copies and interaction ability as the important measurement indicators in applications.

Table.2 measurements of five typical media networks

M-nets type	Number of sub-nets ***X***	Number of lecturing sessions ***Y***	Number of accepted copies ***Z***	Power factor ***e***	Interaction ability ***r***
Broadcasting	1	1	n-1	n-1	0
Client/Server	n-1	n-1	n-1	1	0
Phone-like	$n(n-1)/2$	$n(n-1)$	$n(n-1)$	1	1
Single-producer P2P	2^n-n-1	2^n-n-1	$n2^{n-1}-2^n+1$	$(n-2)/2$	1
Multi-producer P2P	2^n-n-1	$n(2^{n-1}-1)$	$(n^2-n)\,2^{n-2}$	$(n-1)/2$	1

The number of sub-nets in broadcasting, C/S, phone-like and P2P media networks has constant, linear, quadratic, exponential magnitudes respectively, the relationship is $1\leqslant O(n)\leqslant O(n^2)\leqslant O(2^n)$, $n\geqslant2$.

The number of lecturing sessions in broadcasting, C/S, phone-like, one-producer P2P and multi-producer P2P media networks has constant, linear, quadratic, exponential, hyper-exponential magnitudes respectively, the relationship is $1\leqslant O(n)\leqslant O(n^2)\leqslant O(2^n)\leqslant O(n2^n)$, $n\geqslant2$.

The number of accepted copies in broadcasting and C/S, phone-like, one-producer P2P and multi-producer P2P media networks has linear, quadratic, hyper-exponential, ultra-exponential magnitudes, the relationship is $O(n) \leqslant O(n^2) \leqslant O(n2^n) \leqslant O(n^2 2^n)$, $n \geqslant 2$. Broadcasting and C/S M-nets have the same number of accepted copies (n-1) as shown in table 2. In P2P M-nets (either of single-producer or multi-producer), the number of accepted copies have directly across the exponential level to hyper-exponential magnitude, especially, the magnitude of the number of accepted copies in multi-producer P2P M-nets has reached to ultra-exponential. This has fully revealed the immense communication and self-organization abilities of P2P M-nets (Christian P. and Christian B.,2005). For example, in the multi-producer P2P M-nets such as a micro-blog or a social community with ten members, the total number of accepted copies is $(10^2-10)2^{10-2}=23040$. Though 20,000 copies could be regulated, when the number of members extends to a hundred, the number of accepted copies could be astronomical, more than 3×10^{33}. Apparently, it is extremely hard to regulate using traditional method, not to mention that the number of the members in a typical social community (or a microblog) is more than 5,000. Take face-book as an example, it has a member set of 350 million, 55 million entries updated every single day, and shares 3.5 billion copies every week(Qi H and Qibing W.,2010).

The information power factor in broadcasting M-nets is the highest followed by the one in P2P M-nets. The broadcasting effect does not exist in C/S and phone-like M-nets, so their information power factors are one. It can be concluded that, although broadcasting has poor extensibility, its information transmission efficiency is pretty high. This is in accord with the information transmission in real life.

At last, apparently, internet-based P2P M-nets have strongest interaction abilities followed by the phone-like M-nets while the broadcasting and C/S M-nets scarcely have any interaction abilities.

In summary, we believe that P2P M-nets has the strongest transmission ability no matter from the perspectives of network diameter, time delay and throughput rate, or from the perspectives of accepted copies(implied scalability), information power factor and interaction ability. Of course, the other types of M-nets have their own characteristics and advantages in certain respects (broadcasting M-nets has the strongest information power factor while C/S and phone-like M-nets are simple and controllable.).

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