When Encryption is Not Enough

Effective Concealment of Communication Pattern, even Existence
(BitGrey, BitLoop)

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Abstract: How much we say, to whom, and when, is inherently telling, even if the contents of our communication is unclear. In other words: encryption is not enough; neither to secure privacy, nor to maintain confidentiality. Years ago Adi Shamir already predicted that encryption will be bypassed. And it has. The modern dweller of cyber space is routinely violated via her data behavior. Also, often an adversary has the power to compel release of cryptographic keys over well-exposed communication. The front has shifted, and now technology must build cryptographic shields beyond content, and into pattern, even as to existence of communication. We present here tools, solutions, methods to that end. They are based on equivocation. If a message is received by many recipients, it hides the intended one. If a protocol calls for decoy messages, then it protects the identity of the sender of the contents-laden message. BitGrey is a protocol that creates a "grey hole" (of various shades) around the communicating community, so that very little information leaks out. In addition the BitLoop protocol constructs a fixed rate circulating bit flow, traversing through all members of a group. The looping bits appear random, and effectively hide the pattern, even the existence of communication within the group.

Introduction

We have fought for freedom in the physical world, and now the war moved to cyber space. Thesis: if everything you do, say, move, think -- is known to everyone including those who wish to limit you in some way -- then you don't live in the land of the free. We are witnessing the stunning technology of big data that can gobble in the wealth of personal activity and spit out a chillingly accurate prediction of its subject's next move, and when he will do what, when smile, when cry, even when die. If someone knows so much about us, they have a means of controlling us, and freedom it is not. A basic measure of privacy is essential.

Since the big data technology is unstoppable, the battleground moves to the raw material -- the data. The only way to protect freedom is by denying others a full view of everything about us. And we call upon technology to help. We need the means by which we can conceal at least some of what we do, act, say, and go. And for that encryption is not enough. We reveal our soul, so to speak, through metadata, through disclosing when we said what to whom.

What is true on a personal basis, is true on a larger scale, business, organization, and national security. While each detail of our action by itself is not revealing a whole lot, the compendium of these unclassified data is what big data uses as raw material to crunch and simulate our future actions.

It is that important to come up with solutions to hide, to conceal, at least some, of what we do and say. This discussion is presenting such means.

We present two complementary concepts: BitGrey and BitLoop. In both it is clear that concealment occurs, and in that it is different from steganography. The claim is that the apparent communication pattern offers fundamental equivocation that denies its cryptanalyst the ability to discern who is sending messages to whom, when, and for how long, as well as who received which message, if at all. The adversary will hammer the data flow and the BitGrey and BitLoop protocols will keep hiding it. A sufficiently powerful adversary may obliterate the privacy protocols, but arguably cannot crack them.

There are numerous instances where people wish to hide their communication pattern in order to successfully achieve a particular goal. However, it is being claimed that practicing these protocols is also important as generic means to frustrate the numerous "data vultures" that as a matter of course collect any and all information about us in order to successfully build a model of our decision making to be exploited for their aims.

This presentation is focused on the protocol, application discussion will follow.

Related Work: Multi party communication (MPC) is a rich research field with some proximity to the situation at hand, but too far for any practical reference. [1,11] The challenge addressed in MPC research is how to emulate a trusted broker to mitigate among mutually mistrustful participants. And that for the purpose of establishing inner group communication. To the extent that the participants are not fully mutually revealing, the resultant communication may hide some patterns by the anonymity of the communicators. This effort relates more to the well established field of de-anonymizing communicators, usually by tracking statistical behavior. The idea being that an encrypted message sent by an unknown sender establishes the desired security. This in practice is not very convincing. Party identities can be hidden for only so long. Eventually everyone has an idiosyncratic behavior and is exposed. The fully exposed communication pattern then would work against them.

A closer research effort relates to the old craft of steganography [18: hiding the very existence of communication. There is a rich body of literature, and many creative means are known to communicate in stealth. The practical problem with these methods is that they generally don't scale well, and often rely on ad-hoc creativity, while being irreconcilable with a rigid protocol.

The solutions presented here don't hide the fact of communication. In fact the very application of BitGrey or BitLoop assert the use of hidden communication. The resultant communication dynamics hides the communication pattern within the communicating community, accompanied by the assertion that it cannot be cracked beyond the appraised combinatorial vulnerability of the underlying ciphers. In practice, the claim is that the protected communication are sufficiently blurred and unextractable by an adversary, given the underlying cryptographic assumptions.

The closest literary reference to BitLoop is the "winnowing and chaff" by Rivest. On which this solution is built. [5,13]

This work relies on material presented in the various publications that describe the underlying ciphers, as well as the fundamental idea of BitLoop. [3, 4, 6, 8, 9,12,14]

BitGrey: Concealing Communication Patterns in a Multi-Party Community

Hiding the identities of senders and recipients of messages.

Overview: We discuss two variations (chain of delivery, and public ledger) to the same idea where a large number of recipients of a message would conceal the identity of the one or few for whom the message was intended and who could properly decipher it. An eavesdropper would not have means to distinguish between the intended recipient and the decoy recipients. In one way the message traverses through many recipients, in the other, the message is downloaded by many from a public ledger. Sender's identity is concealed by having parties send decoy (random) messages that follow the protocol of content-loaded messages. The protocol allows for a monetary incentive for the concealment, paid either by the sender or from a community fund.

Introduction

Public privacy has been so seriously violated that residents of cyber space all but reconcile with their data nakedness, and deep exposure. Alas, as much as technology took our privacy away, it should be called upon to restore it back, at least in part. While encryption is touted as the main weapon in the privacy arsenal, it is far from being sufficient. Anyone with a handle on how much we say to whom and what messages we receive from which source, will have a pretty good reading on who we are. It is therefore that we need to focus on hiding our communication pattern, which is the topic herein.

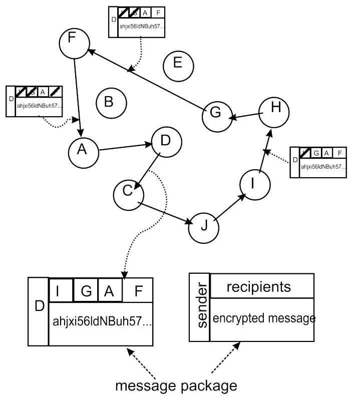
Let's first focus on a method to hide the recipient of a message. This applies mostly for the case where the message one sends is encrypted. A "Dear John" letter is clearly addressed to John. A cryptogram does not inherently reveal whom it is intended to. If a powerful adversary is aware that Alice sent an encrypted message to Bob, then the adversary can apply all sorts of pressures on both Alice and Bob, to reveal the contents of their message. But if the very same message was read by Bob and by a ten more readers, then each reader may claim that the message was not meant for him or her, and Alice can come up with an exculpatory story. Alice defense is even stronger if 1000 readers consumed her message. So what is left to figure out is a mechanism for getting all those "non-decoy" readers to take the message in and effect the confusion.

We present two such mechanisms: (1) chain of delivery and (2) public ledger. In the first Alice messages bounces off the decoy readers and the intended readers, and in the second all the readers download the protected message from a public ledger. Since in either way this action is a burden on the decoy readers, this should be accomplished either (1) through community service where one helps others, expecting others to help him or her, or (2) through a monetary incentive. The latter enjoys the advantage of allowing Alice to increase the degree of equivocation (the number of decoys) by offering a larger sum for these decoy services.

The overall BitGrey equivocation protocol may call on parties to randomly send random message towards a sufficiently large number of recipients. This practice would arm an interrogated sender with a valid explanation to any real message he or she sent, and amount to concealing the identities of parties who send content-loaded messages.

Definitions: The environment of reference is comprised of a community of communicating, or potentially communicating parties. The parties may be referred to as "nodes" or "readers" and the community as a "network". This community might in fact be a sub-community of a larger community, and the parties may be human or devices. There assumes to be a viable privacy threat: an agent who aims to learn about the community through its communications: content and pattern. The privacy threat agent (also referred to as "privacy killer") assumes to have access to the messages that flow back and forth within the community.

It is generally assumed that the messages involved are robustly encrypted, and the privacy killer remains challenged by the encryption, namely the contents of the message remains secret, only the pattern of their dispatch is exposed. It is further assumed that the privacy killer is in a position to extort the nodes and demand full disclosure of the content and the parties of the messages. The envisioned defense for the sender is (1) the message is a random string, meaningless, and (2) the recipients were selected randomly as either participation in the privacy promotion practice or as a revenue generator. The envisioned defense for the recipient of the message is that (1) the recipient can't read it because it was not intended for him, and he has no keys to decipher it, if indeed it is a meaningful message and not a random sequence.



Chain of Delivery BitGrey Protocol

The term communication pattern reflects information regarding the identities of the communicating parties (sender and intended recipient), size, timing, and back and forth sequences of the running messages.

Chain of Delivery BitGrey Privacy Protocol

In this mode we distinguish between "pre-address" and "post address" modes. In the first mode the sender identifies a series of recipients and releases the message within the community. Any party (node) that does not find itself on the recipients list passes the message further. Any party that finds itself identified on the recipients list will mark on the message that it read it, and then pass it on. The party that is the last to mark itself as having read the message will return the message to the sender, to assure the sender that all the designated recipients became aware and read the message. Among the parties who read the message there exists the one or more who were the target recipients. But this distinction does not leak outside. Some designated readers will not be able to extract content from the message because they don't have the right keys.

In the post address mode the sender releases the message to the community, and each party marks as 'read' once receiving the message. The message keeps being pushed from one party to another until the entire community has read it, and then the message returns to the sender. This is feasible in smaller communities.

Note that this protocol does not specify any particular route for the message within the community.

Public Ledger BitGrey Mode

In this mode Alice posts its message on a public ledger from which a sufficient number of readers download it.

Recipient Targeting

For the BitGrey protocol to work it is necessary for reading nodes to be able to discern between messages intended for them as recipients and messages not intended for them, or decoy messages that are not intended for any reader, and are there to confuse the privacy threat agent. This distinction cannot be as a plain tag on the message itself, since the privacy killer will be able to read it too. Even an encrypted tag is not a very robust means of distinction. Any such static designation will be quite readily identifies by the adversary.

We conclude then that the distinction of being an intended reader of a message must be based on something privately known by each reader (not by anything in the message itself). A simple way would be to have any reader decrypt an incoming message with its privately held key, and if it makes sense then it is intended for that reader. If it reads as gibberish then not. This is not a very clean method because some content may be borderline; it may look random, but it really is a message of good contents, only with appearance of randomness. There would be too many errors and the distinction may be too complex. What is needed is a clear-cut distinction between message intended for a particular reader, and all other bit strings. This requires a suitable cipher.

Recipient distinction may occur via one of two modes:

1. decoy tolerant ciphers
2. composite ciphertext

The decoy method is simpler and will be discussed below. The composite ciphertext is a more involved solution, but with rich opportunities for managing the community. It will be discussed ahead.

We define a "Decoy Tolerant Cipher" as a cipher which quickly, easily and unequivocally distinguishes between proper message bits and decoy bits. The former it decrypts the latter it discards.

Decoy Tolerant Cipher

Normally ciphers are designed to decrypt everything fed into them by way of ciphertext, assuming all the feed is bona fide decryptable material. A Decoy Tolerant Cipher, by comparison, is a cipher that is designed to quickly winnow the wheat from the chaff -- to use the expression first introduced by Ron Rivest [13] -- and only decrypt the wheat. The faster and more efficient the classification (wheat, chaff) the more tolerant the cipher to very diluted message streams, where the wheat drowns in the chaff. And the more so, the greater (1) the cryptanalytic challenge for the cryptanalyst, and (2) the greater the power of the applicable protocol to carry out special tasks, like the one envisioned in the BitGrey protocol.

BitFlip as a Decoy Tolerant Cipher

BitFlip is a poly alphabet cipher. [12, 9]. Each letter of each alphabet is comprised of a distinct (secret) bit string that counts m bits. Each letter of each alphabet is associated with a target Hamming distance h. All the strings that have a Hamming distance h from a given letter are evaluated to this letter. A string of s bits that does not evaluate to any letter in a recipient's alphabet is regarded as nonsense and discarded. Same for strings that evaluate to more than a single letter. BitFlip, hence is inherently a decoy tolerant cipher.

Composite Cipher

We consider a situation where n plaintext messages, P_1, P_2, ...P_n are encrypted via some ciphers with the respective keys K_1, K_2, ... K_n, to generate n respective ciphertexts C_1, C_2, ... C_n. We now consider a "consolidated cipher" , CC, which takes in as input the n plaintexts, and the n keys, and generates as output a "composite ciphertext", C^n.

$$C^n = CC\,(P_1, P_2, ...P_n, K_1, K_2, ...\ K_n)$$

We further consider n corresponding decryption procedures DEC_1, DEC_2, ... DEC_n, such that DEC_i (i=1,2,..n) takes in the composite ciphertext and generates P_i as output.

$$P_i = DEC_i(C^n)$$

This is a composite cipher environment.

A composite cipher environment offers a unique security advantage: equivocation. An attacker in possession of the composite ciphertext may at most 'crack' the ciphertext to the point where all k keys are identified, and all the plaintexts are known. Yet, the attacker will not be able to learn from the composite ciphertext which of the n plaintexts, were actually read by a particular recipient of the composite ciphertext. This distinction depends on which of the k keys a particular recipient was using. That key is not communicated, and is not identified in the ciphertext among the other (n-1) keys.

To sharpen the inherent security within a composite ciphertext, we may think of Alice giving Bob instructions to move in one of the four directions North, South, East, or West. Alice will identify four plaintexts P_1, P_2, P_3, P_4 each directing Bob to take one of these four directions. Using a composite cipher Alice will generate ciphertext C^4. Alice previously exchanged key K_3 with Bob, and so she knows that Bob will evaluate C^4 to P_3 and therefore move East. However, an attacker capturing C^4 will not know which of the four keys is used by Bob. So for the attacker -- however smart -- the situation is fully equivocated. Bob will be regarded as having equal chances to go in any of the four directions. This equivocation is inherent in the composite ciphertext, regardless of the particulars of the cipher.

A C^n composite ciphertext may in fact be evaluated to 2^n-1 plaintext messages. This is because any combination of $0 < m \leq n$ plaintexts selected from the n plaintext P_1, P_2, ... P_n may be regarded as a distinct plaintext evaluated from the same composite ciphertext.

Let plaintext P_i be an instruction from Alice to Bob to move from where he is located according to a specified vector V_i (length of movement and direction of movement). For every combination of the 2^n-1sets of plaintexts, Bob will be moving to a particular spot in the space where his motion is taking place. This challenges an attacker with equivocation marked by 2^n-1 distinct spots.

Key combinations allows one to build a confidentiality cascade. An arrangement where one class of recipients [1], is given key K_1 while a second, "higher", class of recipients, [2], is given keys K_1, and K_2. Readers from class [2] can read everything class [1] reads plus more content that class [1] cannot read. Similarly class [i] will be given keys K_1, K_2, ... K_i, so they can read everything that classes [1], [2],....[i-1] reads, plus content that these lower classes don't read.

We present some ciphers that may be used to construct a composite ciphertext environment.

Illustration: Let C^4 be a composite ciphertext over the four plaintext messages, relating to movements over a Cartesian map: 1. move 1 meter to the right, 2. move 1 meter upwards, 3. move one meter to the left, and 4. move one meter downwards. Alice sends this composite ciphertext to Bob. A smart attacker intercepts this composite ciphertext and prepares a map that lists all the possible locations that Bob may be instructed to be, following the instructions in the composite ciphertext. The list shows 9 distinct outcomes. The attacker cannot further limit this list by extracting more information from the captured composite ciphertext.

Key Combinations	Bob's Coordinates:
1	(1,0)
2	(0,1)
3	(-1,0)
4	(0,-1)
1, 2	(1,1)
1, 3	(0,0)
1, 4	(1,-1)
2, 3	(-1,1)
2, 4	(0,0)

3, 4	(-1, -1)
1, 2, 3	(0,1)
1, 2, 4	(1,0)
1, 3, 4	(0, -1)
2, 3, 4	(-1,0)
1, 2, 3, 4	(0,0)

Had the four instructions be +1, to the right, +2 upwards, +3 to the left, and +4 down, the table would look like: .

Key Combinations	Bob's Coordinates:
1	(1,0)
2	(0,2)
3	(-3, 0)
4	(0, -4)
1, 2	(1, 2)
1, 3	(-2, 0)
1, 4	(1,-4)
2, 3	(-3, 2)
2, 4	(0,-2)
3, 4	(-3, -4)
1, 2, 3	(-2, 2)
1, 2, 4	(1,-2)
1, 3, 4	(-2, -4)
2, 3, 4	(-1, 0)
1, 2, 3, 4	(-2, 2)

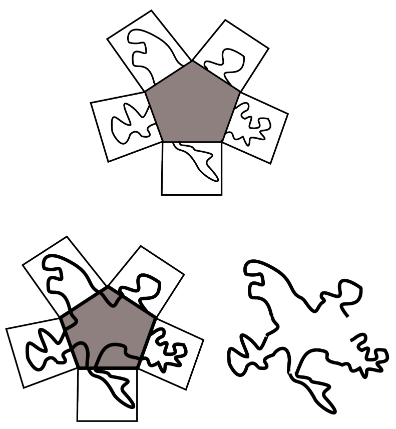
where the equivocation is over 15 distinct options.

BitMap Composite Ciphertext Cipher

BitMap [Appears as "Denial Cryptography", as "Cryptography of Things", as "At Will Intractability Cryptography" and as "Drone Targeted Cryptography", see 14, 17, 8, 4] inherently generates a ciphertext larger than its plaintext. It is easy to increase the size of the ciphertext with many letters sequence that collapses into a single letter. This is done by marking a path on the BitMap graph where the path traverses vertices which are of the same letter. This means that for a given decryption key the input (ciphertext) flow may have as many superfluous letters (bits) as desired.

Here is one way to use BitMap to build a composite ciphertext. The procedure starts with generating a BitMap pathway (ciphertext C_1) to represent the first plaintext, P_1. Then generating a BitMap pathway (ciphertext C_2) to represent the second plaintext P_2. Let a vertex marked X be any vertex in the C_1 path. One would then expand that vertex (replace it) with the map used to draw pathway C_2 on, and draw C_2 on that map, such that C_2 is grafted into C_1. When preparing the key for the P_1reader, all the vertices which are part of the C_2 map will be marked as X. This will insure that the combined pathway C_1 + C_2will be interpreted as P_1. For the reader of P_2, one will mark as letter X all the vertices in the first map, used to draw C_1, and leave the vertices in the second map, where C_2 is drawn untouched. This combined map (key) will insure that the intended P_2reader will interpret the combined $C_1 + C_2$ composite ciphertext as P_2.

BitMap Composite Ciphertext Key Construction



This grafting can continue at any spot of the combined $C_1 + C_2$ pathway, and generate $C_1 + C_2 + C_3$ composite pathway, and so on for all n plaintexts. The composite ciphertext $C_1 + C_2 +..... C_n$ will be evaluated to P_i (for i=1,2...n) through K_i constructed as described herein.

A second method is described here: In order to use BitMap for this purpose it would be necessary to prepare a key that would be able to handle any message sent for any key. One way to do so is to construct a BitMap key comprised of (n+1) regions, fitted to handle n participants with n keys. The BitMap key will be comprised of a central n-sided polygon, where each edge of the polygon will be a basis for a key that can be used to describe any message of any size. These n keys will be spread each off their respective edge of the polygon. They will be regarded as specific keys. All the vertices in the internal n-sided polygon will be marked with one letter, say X. Also all the vertices that make up the n edges of the polygons will be marked as letter X.

Each party will receive the same key (comprised of the internal polygon and the n specific keys). Party i will receive a key such that its specific area will be marked with the letters of the alphabet according to the terms of the BitMap cipher, namely such that any message of any length can be fully encrypted in each of the n specific keys. All the vertices others than those comprising the specific area for the party, will be marked as the letter X.

In summary, the n parties will be using the same geometric structure as key, only that for each party only its own specific section will be marked with the full letters of the alphabet, while all the other specific sections, as well as the internal polygon will be marked as letter X

It will be required to dictate that every message for every party will start with one vertex marked X and part of the edge of the polygon. Also all messages will have to end up at a vertex that is part of the same edge. This can always be achieved, by padding any message with an agreed upon number of letters that should be discarded upon decryption, and are there only in order to allow the pathway (the ciphertext) to extend so that it ends at the edge of the polygon.

To construct the composite ciphertext one will mark the n pathways (ciphertexts, C_1, C_2,...C_n) each on its own section of the overall key. Next the n pathways will be threaded to a single pathway. This will be done by connecting the end point of pathway C_i with the starting point of pathway C_{i+1}. (for i=1,2,...(n-1)). The connection will be done in any way that traverses through only universally X marked vertices on the polygon or its edges. A universally marked X vertex is a vertex that is marked as X for all the n parties.

Such threading of the n pathways (C_1, C_2,....C_n) to a single composite ciphertext C^n will conclude the encryption. C^n will then be used in the BitGrey protocol. The composite ciphertext may be passed to all the parties. Each party i will be blind to all the individual pathways (C_1, C_2,..C_{i-1}, C_{i+1},..C_n) that comprise C^n, and see only its own pathway, C_i which it will correctly decrypt to P_i.

BitMix Composite Ciphertext Cipher

BitMix [17] is a complete transposition cipher. It features a key space of size |K| =p! applicable to transpose a series of p data elements to any of the possible p! permutations. Let us now construct a composite plainext as follows:

$$P^{ni} = P_1 - P_2 - .... P_i - * - P_{i+1} -..... P_n$$

comprised of the n plaintexts P_1, P_2,.... P_n and a 'separator element', "*", which is placed between P_i and P_{i+1}. The interpretation of P^{ni} will be as follows: the instructions expressed in the plaintext messages that are placed left of the "*" separator should be regarded and followed and all the plaintext messages that are placed right of the "*" separator should be ignored.

There are 2^n -1 distinct such P^{ni} composite plaintexts. Let P^{nm} be one particular composite plaintext. Let us now encrypt P^{ni} using BitMix. This will be effected through a transposition key K_m, and will result in a composite ciphertext C^{nm}.

Because BitMix is a complete transposition ciphertext there is a definite and unique key that transposes every one of the 2^n - 1 possible composite plaintexts to the same composite ciphertext C^{nm}. An attacker will not be able to extract from the composite ciphertext the key that was actually used to create C^{nm}, and will face an equivocation over the 2^n - 1 possible composite plaintexts.

BitFlip Composite Cipher

BitFlip is a super polyalphabetic cipher. Each of the n recipients is using a set of distinct alphabet. Each letter of the ciphertext will be evaluated as a proper letter only by one of the n recipients; the other would discard this letter. So a sender can put together a composite plaintext comprised of n distinct message, M_1, M_2, ...M_n, encrypt the letters of each message with the key used by the intended recipient such that each recipient will discard all the letters except the ones intended for her, which she will evaluate correctly.

The BitGrey Protocol

A community of communication parties (a network) may activate the BitGrey protocol to conceal the information regarding their communication pattern. It is activated when the community wishes to hide such information from outsiders, and also from "insiders". The latter refers to the situation where parties in the communities are aware of messages they send or receive, but know not who sends other messages to whom. This situation is accomplished by lack of knowledge of cryptographic keys. A community may share cryptographic keys and thereby hide the communication pattern only from outsiders, or a community may have degrees of mutual secrecy of such keys.

The BitGrey protocol has two parts: (i) recipient concealment, and (ii) sender concealment.

Recipient Concealment

Recipient concealment happens either through decoy-tolerant ciphers or through composite ciphers. In both ways a message can be sent to as many parties as desired, and only the intended party, or parties will interpret the communicated ciphertext into the plain message sent out by the sender. The others will either treat such message as random bits, or realize it is a message not intended for them.

Since the ciphertext is evaluated by each party in private, an outsider who traces all the communication among the parties will not be the wiser as to who is the party that evaluated the ciphertext to its intended message.

Upon interrogation each party that received the message can claim that it checked it out and it did not amount to any message they could read.

The larger the number of recipients of the ciphertext, the greater the equivocation, the greater the cryptanalytic confusion, and the greater the entropy.

Sender Concealment

In order to conceal the event of sending a meaningful message within the community, the protocol calls for the parties to randomly compose decoy messages (random bits) and execute the recipient concealment protocol, sending that decoy message to others as if it were a meaningful message. All the recipients of this decoy message will discard it.

This randomized decoy operation will allow each sender to respond to interrogation with the claim that what they sent was part of this sender concealment as called for by the protocol. Thereby insist that there is no plaintext to be revealed, since the ciphertext is meaningless.

Shades of Grey

The interplay between sender-concealment and recipient-concealment will determine the 'shade of grey' in the protocol. We first discuss the boundary conditions: 'almost white grey' and 'black grey'.

'Almost white grey' state is when sender-concealment is practiced at a minimum, or even not at all. As long as the protocol calls upon parties to randomly send decoy messages to parties in the community then any sender, under interrogation can say -- that what I did. If that is the state of sender concealment then an outside observer will have good reading on the level of communication that transpires within the community. The recipient concealment will prevent the observer from finding out who received which message, but the overall intensity and characteristics of the community communication will be rather exposed.

The 'black grey' state is when sender concealment overwhelms real messaging. So much so that the latter becomes an undetected 'noise' within the dynamics of the former. To practice a 'black grey' protocol a community at time point t_s will start a barrage of sender concealment decoy messages, and continue with it until some end point t_e. At Some time point $t_b > t_s$ the community will begin to send real messages among its parties, as needed by their circumstances. At time point $t_f < t_e$ the community will finish sending the real messages. During the interval of t_s to t_f the flow rate of meaningful messages will have to be much smaller than the decoy messages so that the real messages will be concealed through having no statistical distinction over the normal noise of the decoy messages. So practiced, the 'black grey' state will reveal to an outside observer that some time between t_s and t_e there was probably some meaningful communication within the community, but the window t_b to t_f will not be exposed, and neither will the pattern of such communication.

Black-grey state may be expensive to uphold, it requires a lot of stray flow of random bits, so in practice communities will decide per the significance of the matter they wish to conceal, what is the optimal shade of grey for their situation, namely to decide how many decoy messages to use.

Applications (BitGrey)

Applications of the BitGrey protocol may be classified by whether they are used for internal segregation or for defense from external eavesdroppers. Also, whether the community involved is large or small.

The protocol may be operated with a monetary incentive.

Key Management

The BitGrey protocol calls for n parties to have n cryptographic keys. Some or all of these keys may be the same. If all the keys are the same (just to prevent outsiders from reading the community messages) then the addressee must be identified in the plaintext. If no two keys are the same, there is no need to identify the recipient (addressee) in the plaintext. Some parties may possess the keys of all the rest, some may posses the keys of only a few of the parties. Even if a party has only the key of one other party, it can still participate in the BitGrey protocol, because the adversary does not know how many keys each party has.

The community may be managed through a key management table that identifies which keys are known to which party. For example a community comprises of parties A, B, C, and D having keys K_a, K_b, K_c, and K_d respectively may be managed through a matrix like below

Key / Party	A	B	C	D
K_a	X			X
K_b		X		X
K_c	X		X	
K_d	X	X	X	X

Party A can send message to everyone. Parties B and C can only send messages to party D, and party D can send messages to everyone except to party C.

Monetary Incentivized BitGrey

We consider two options: (i) community funds, and (ii) peer to peer payment. In the first mode one establishes a community fund from which to incentivized parties to participate in the BitGrey protocol. In the second mode the parties themselves pay to other parties. A combination of these two modes is also possible.

Community Funds: The community funds will pay parties to send decoy messages that look like content-loaded messages, and do so in order to achieve the desired "shade of grey" as discussed above. The community funds will incentivize parties to pass read messages forward to marked readers who have not yet read the message.

Peer to Peer Payment: A sender may wish to protect its message with a very active BitGrey protocol and to that end will pay other parties the way a community fund would have paid them.

BitGrey Money: The money incentivizing BitGrey practitioners will be digital money. BitMint platform is ideal because it pays at any desired resolution in a frictionless manner, and requires participation of only the payer and the payee, no need for a third party authenticator.

Enterprising BitGrey

The BitGrey protocol may be enterprised and monetized as a service for a community. The BitGrey service provider will design the details, select ciphers, assign keys, and incentivize parties to support the protocol through monetary compensation.

BitLoop: Zero Information Leakage of Network Communication Activity

Multi-Party Communication Where the content, the pattern, and even the existence of any inter-party communication is concealed despite complete capture of all the communicated bits.

A group comprised of g of well ordered members i=1,2,...g will experience a circular fixed bit rate, C (bits/sec) communication flow such that each party, i, contributes c_i = C/g bits/sec, and removes its bits when they are returned to it following a full circle. The c_i bits/sec comprise m_{ij} for j=1,2,..(i-1),(i+1),...g bits/sec which carry content (message bits) for up to each of the other (g-1) parties, and d_i bits/sec which are decoy (random) bits. $c_i = \Sigma\, m_{ij} + d_i$. Each party j identifies all the messages intended to it: m_{1j}, m_{2j},..... m_{nj}, and ignores all the other bits. An eavesdropper will see a fixed circular bit flow which may be totally decoy -- meaningless, or may harbor any pattern of communication between any two or more of the n members group. As long as all the circulating bits appear random enough, the group does not leak any information regarding their internal communication.

Introduction to BitLoop

We address a situation where a group of g members, agents, wish to hide their internal communication in a situation where the communicated traffic is exposed. If all the communicated bits are content-loaded, then their flow is quite revealing, even if the bit flow retains their content concealed owing to uncompromised encryption. The content-laden bits identify who is talking to whom, how often, and in what configuration relative to other messages back and forth.

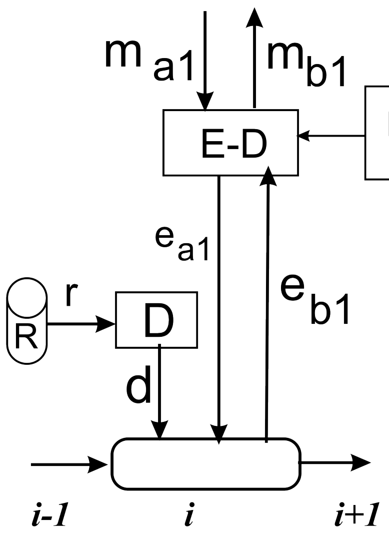
To prevent this leakage of information the group of g members may mix their content-laden bits with random, or so called, decoy bits. The mixing will have to be such that the eavesdropper will not be able to distinguish between decoy bits and content bits, but the group members (agents) will readily carry out this distinction.

To achieve this goal, we propose the BitLoop protocol. It will render the group into a "black hole" in as much as they won't leak information about their communication pattern throughout the application of this protocol.

The BitLoop protocol requires encryption, which in turn can be used to send messages to one or few designated recipients, and not to the others -- depending on key distribution. In the basic mode the agents share a single encryption key, and hiding is projected only toward outsiders.

Loop Flow

We consider g members of a group fitted in order: 1,2,....g. Member i is considered as communicating C bits/sec to member (i+1), for i=1,2,...(g-1). Member g is passing C bits/sec to member 1. So described there forms a flowing loop, in a steady state, given that the identities of the bits is ignored.



Functional Components of a BitLoop Member

We first assume the baseline state where all the bits in the loop are randomly selected, and the bits that flow from one member to the next are the same. In that case the only information that leaks outside the group is the order of the group and the rate of bit circulation. However such a state does not allow the members of the groups (the nodes) to exchange any messages. We therefore advance the state by allowing several bits to flip between nodes. An outside observer will be able to monitor how many and which bits have flipped. This observation will amount to information leakage if the bit flipping correlates to content, to communicated messages. However, if the bits flipped by each node are also randomized, then they leak no information, except the count of how many bits flipped. Alas, this will be the only information gathered by the nodes themselves.

The interesting state happens when the nodes use a protocol where the flipped bits are indistinguishable from a random flow, but in fact they convey information. We present a content-hiding bit-flipping protocol: BitFlip [5, 9,12]. The BitFlip protocol is activated within the BitLoop protocol that insures a loop flow of a fixed bit rate, where a random number of bits are flipped as they pass from one node to another. Overall the group runs a communication regimen where each member of the group communicates with any other, and none of the prevailing patterns leaks.

The BitLoop Protocol

We first describe this protocol in its steady state then how to get it started and how to stop it.

In a steady state a flow rate of C bits/seconds circulates through the members of the group. The members are set in a fixed order 1,2,...g. Each member passes the full bit flow of C bits/sec to the next member in order. Member g circulates back the C bits/sec to member 1. So the bit stream flows from member i to member (i+1) for i=1,2,...(n-1). Each node contributes C/g bits/seconds to the flow. Each node in turn removes the bits it contributed to the flow in the previous round, and replaces them with new bits. That way the flow rate is kept stable (C bits/sec), but the contents is refreshed every cycle.

In its steady state each of the participating circulating nodes takes in the incoming bits as a sequence of blocks, each block comprises s spans, and each span comprises n bits. The span is the basic data unit processed by BitLoop. The number of bits in a block is |b|=ns. Each node analyzes the s spans in a block one by one. For each span the node first decides if this is a span of bits it put in, in the previous round. If it is -- then the span is removed, and another span replaces it (how to choose the replacement span will be discussed ahead). If the span is not one that was put there by the examining node, then it will be evaluated by the BitLoop cipher. The BitLoop cipher is either a composite cipher, or a decoy-tolerant cipher. Either way the result of the evaluation is either null (no message taken in), or positive -- namely the evaluated span is converted to a content-laden message (plaintext) or part thereto. Message parts in such plaintext form are then concatenated to form the full message sent to the examining node. That is how messages from other members in the group are passed to the examining node.

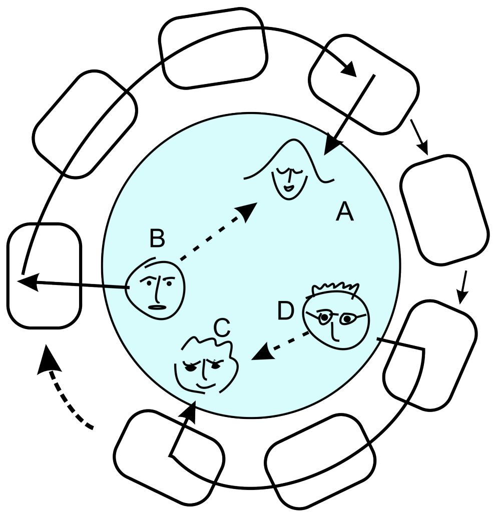
So operated the Loop Flow is a fixed bit rate moving in order from group member to group member (node to node). Each span flows through each member in n/C seconds. Assuming no delay in the communication lines, the time it takes a span to fulfill a full round is gn/C seconds. Every circulating span (and every circulating bit) has a life span of one round. The circulating bits are removed by the member that put them up when they are returned to the member that put them. Every span of bits put up by any member is passing through all other members. Such spans may be completely random (comprised of random bits) and so no member will extract any meaning (plaintext) from it. A span can be a ciphertext, which does hold the content of its respective plaintext. In that case all the members who are equipped with a fitting decryption key will extract from it the encrypted meaning. Others would not.

The idea of this loop protocol is that from the outside the flow is at constant rate with a random number of bits that get flipped as one member passes the flow to the next. The users of this loop protocol intend to deny any visibility to an outside observer as to which member talks to whom, how much, how often, in what configuration. The appearance of the flow is the same whether all the circulating bits are perfectly randomized or fully content-loaded and for anything in between. This veil is the object of the protocol.

We first describe the "Null State", defined as the state of no communication. None of the g group members communicates with the other. In that state group member i (i=1,2,...g) receives spans at a rate of C/n spans/seconds. (g-1)/g of these spans were put in the stream by some other group members, ("foreign members"), and 1/g of these spans were put into the stream by group member i ("home members"). When member i encounters a foreign span, it regards it as a cryptogram and processes it with her cryptographic key, K_i. Because she uses a BitLoop cipher the output of this process is null -- no plaintext comes out because the bits were randomized. The member then discards the output, but pushes the original (cryptogram) span further, to member (i+1). When member i encounters a span that it recognizes as one it added to the stream in the previous round, then it replaces it with a new randomized span. Note: an issue arises regarding the probability that another member will by chance put up a span that the member falsely recognizes as its own. This probability can be well managed, and at any rate this coincidence will be spotted real time, and handled via a resolution protocol.

So prescribed, it is clear that the lifetime of a revolving span is one round. As soon as it is being returned to the member that put it up, it is removed and replaced. Every member does so, the flow rate of C bits/sec remains fixed, and the Loop is in steady state.

The null state as described involves no information exchange between the members.



Loop Configuration and Functional Conversation

We now describe the method of conversation within the loop protocol. Alice and Bob, two members of the group, Alice is in position i and Bob in position j, (in the group order) wish to run a conversation. Both have unique cryptographic keys, K_a, K_b respectively. They both know each other keys (the keys may, or may not be the same). Alice first message is m_{a1}. She encrypts it with Bob's key to generate its encrypted version $e_{a1} = Enc(m_{a1}, K_b)$. Alice will then divide the cryptogram (e_{a1}) to bit strings comprised of n bits each (padding the last span as necessary): e_{a11}, e_{a12}, ...a_{a1u}. The cryptogram is then written as a sequence of $u= t_{a1}$ spans.

Alice (in position i in the order of group members) now wishes to load the cryptogram e_{a1} to the loop, so that it will reach Bob at position j. To do so Alice waits until she encounters a span she herself loaded up to the flow. Since it is her span, she removes it, but now instead of loading up a randomized span, Alice loads up the first span of her cryptogram for Bob: e_{a11}. This content-laden span, will run with the flow from Alice at position i to member (i+1), then to (i+2). And since the flow is circular, e_{a11} will eventually reach Bob at position j. Since for Bob this span is foreign, he will apply it to a decryption process with his key, K_b. The result will be the respective plaintext m_{a11}.

When Alice encounters the next span she recognizes as her own, she replaces it with the next span from the cryptogram e_{a12}, and this span, similarly, reaches Bob who will decrypt it with his key, K_b to extract the respective plaintext m_{a12}.

This will continue span after span: e_{a11}, e_{a12} ....e_{a1u}. When all the u spans of the cryptograms have been processed, Bob extracts the full message m_{a1}.

All other members of the groups not applying Bob's key to the flowing cryptograph spans from Alice, will interpret these spans as 'null', and simply push them further to their next member.

The loop has a finite capacity, which may be less than u -- the span count of Alice cryptogram -- and in that case Alice will remove from the flow earlier message spans (which Bob has already read), and secure room for subsequent spans of the message.

Bob, wishing to respond to Alice, will activate the same protocol on his part, using Alice's key, K_a, to encrypt his message, and thereby Alice reads Bob's message. To which she can reply.

While conversing with Bob Alice can send messages to Carla and David, and others, using their specific cryptographic keys.

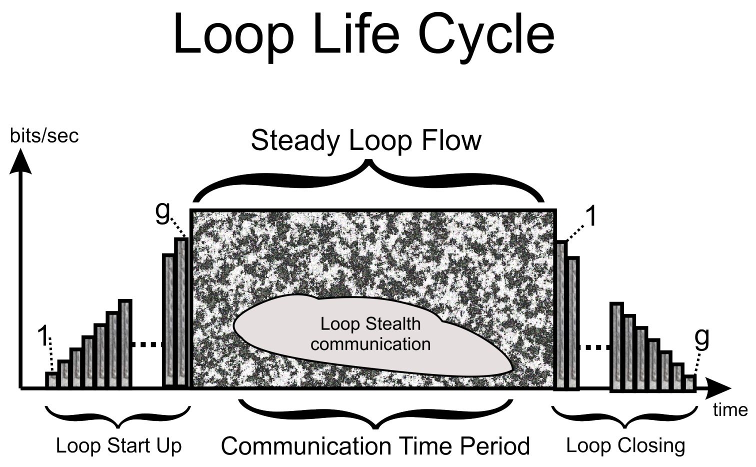
All members of the group will run the same procedure when they wish to communicate with anyone within the group. This is the 'live state' of the loop. It's nominal objective is to hide the communication pattern from outside observers. The idea being that external monitors of the loop (unaware of the cryptographic keys used) will see a random-looking flow that looks the same over time, whether it is in the null state, or in the live state, and regardless of how 'live' the state.

Having described the basic run of the loop, we now discuss the issues of (i) starting up and closing down the loop, (ii) capacity, (iii) probability of confusion. The prime issue of quality and features of the BitLoop ciphers will be addressed in a dedicated section.

Starting Up And Closing Down The Loop

The loop circulation protocol may start with setting up a clear order of the g group members: 1,2,...g. The number of spans per second in the loop is C/n (C is the bit rate of the loop, and n is the number of bits in a span). Member 1 will activate a random number generator and construct consecutive bits strings, counting C/g bits, spread as C/gn spans, (C is the number of bits/second for the loop flow rate). Member 1 will push the generated random bits to member 2, all in a time frame of one second.

Member 2 in the order will prepare the same number of spans, C/gn, also by invoking a source of randomness. When member #2 receives the C/gn spans from member 1, it pushes them on to member 3, adding its own C/gn spans. Member 3 now receives 2C/gn spans. It too generates C/gn spans and adds them to the 2C/gn that came to it from member 2. What goes forth to member 4 is a stream of 3C/gn spans. The described process repeats such that every member in turn passes through the bit flow coming its way, and adds to it, its contribution of C/gn spans (all random bits). The flow thus swells from member to member until it reaches a throughput of C/n spans, pushes from member-g, the last, back to member -1, the first. When member 1 receives the full flow rate of C/n spans (or C bits/sec), then the steady state has been achieved. Next member 1, recognizes the C/gn spans it uploaded in the previous round, removes them and replaces them with new C/gn randomized spans. All subsequent members do the same -- recognizing their own contribution from before and replacing such spans with new ones.



This is the steady state, null state (no communication takes place within the group). It will last until some member decides to say something to another member, and then the loop protocol as described above is activated.

When the BitLoop session comes to its end (the last message was exchanged in this mode), the flow will continue for a while the way it worked before the first message transpired -- a flow of C bits/seconds of randomized bits that contain no content. To end this “after-duty” phase, the start-up protocol will be activated in reverse. The first member would remove the spans it contributed in the previous round, but will not replace them with new spans. As a result the flow from this member 1 to member 2 will be decreased from C/n spans/sec to (g-1)C/gn spans/second. This reduced flow then arrives at member 2. Member 2 does the same, namely it removes the C/gn spans it contributed to the flow in the previous round and offers no substitution for them. The bit flow that goes then from member 2 to member 3 is at a rate of (g-2)C/gn spans/second, Each member in turn will remove the spans it contributed in the last round and push further the remaining span. By the time member g exercises this span removal routine -- there are no more circulating bits left, and the BitLoop platform (the null state) is closing down.

Capacity

The set capacity of the loop C bits/seconds limits the communication throughout of the protocol. One would first determine what is the expected communication load to be served by the loop, and use this figure to design the capacity. In its limit all the revolving spans will be content-laden, no room for sheer randomness. However, if practiced as routine, then this fact will likely leak and the advantage of the loop will be lost.

The span throughput of the loop is C/n spans/seconds, which comes to allocating to each of the g members of the group a communication capacity of C/ng spans/seconds. If this throughput is not enough for a particular member, then it will develop backlog, which can always be alleviated by streaming it outside the loop. We may be looking here at a need to allocate the more sensitive communication for loop-compliance, while routing the rest to more traditional ways of communications.

A problem arises if there is a great variance in communication needs between the members. Some may have a lot to communicate and the loop will not suffice, adn other have little to say, and most of the life of the loop they are 'spinning water' namely uploading sheer randomness, with very little actual communication.

Usually a member that is a target for a lot of communication is also a heavy duty communicator itself, but in times, it may be that a member received a heavy load of loop-communicated messages while it itself is saying very little in return.

Such variety should be well considered for the determination of the desired throughput.

Other considerations include the load to keep the null state and the overall random bit communication.

In some ways the important count is spans rather than bits, and so the value of n (bits per span) is critical too. Especially so in the case where the BitFlip cipher is being used. Generally the decoy-tolerant and the composite ciphers require a large span to operate correctly. Large spans reduce the span throughput per a given bit rate. Also large spans reduce the likelihood that the same span will be issued by two different members. This will slow down the operation, but not stop it. So because either one of the two involved members will identify the problem, and notify the source of this message, requesting a re-send.

BitLoop Ciphers

BitLoop ciphers must satisfy the same requirements stated for BitGrey protocol, namely decoy-tolerant ciphers or composite ciphers. The choice of cipher determines the size of the span. Composite ciphertexts may require large spans.

Implementation

BitLoop needs a project manager to implement it. This manager may be external, or may be member number 1. Activities include system design, and operation control.

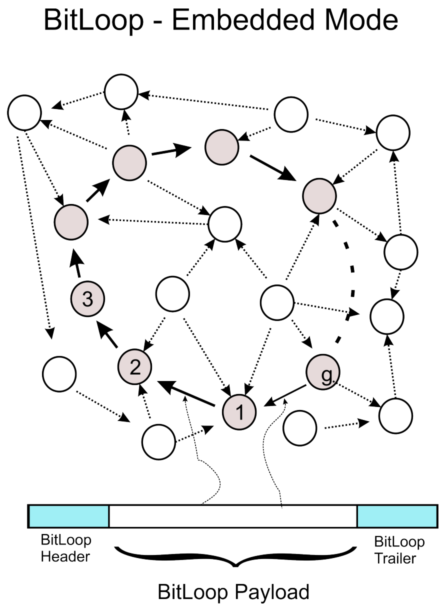
Design includes setting up the bit rate, the span size and the required ciphers. It also includes rules of behavior in case of difficulties like a broken chain, or incantation of a member. In such cases the project manager will need to make sure that a notification of the arising difficulty is disseminated through the group along with a mention of which rule of behavior applies.

In the event that the set bit rate is insufficient, it is always possible to close down the BitLoop session, and restart another with a higher bit rate.

Applications

BitLoop may be used for intense high level communication concealment, or for low-intensity long term application. It may be used on a stand alone basis or in an embedded form.

When applied in an embedded form the communicating spans will have to be identified as such, since they are embedded in additional communication. In that case the spans may be encapsulated in a bit-frame consisting of a header and a trailer. Will be used mostly for low intensity applications.



The BitLoop protocol may be used with complete internal visibility, or with zero internal visibility, or anywhere in between.

Visibility Status Applications

The BitLoop protocol may be used with complete internal visibility, or with zero internal visibility, or anywhere in between.

The case of full internal visibility can be constructed through either a shared key, or a shared key matrix. In a shared key the addressee needs to be identified in the message itself. In a shared key matrix, the identity of the key that properly evaluates the incoming span is the indication of addressee.

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