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RFC 9285
The Base45 Data Encoding

Abstract

This document describes the Base45 encoding scheme, which is built upon the Base64, Base32, and Base16 encoding schemes.

Status of This Memo

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1. Introduction

A QR code is used to encode text as a graphical image. Depending on the characters used in the text, various encoding options for a QR code exist, e.g., Numeric, Alphanumeric, and Byte mode. Even in Byte mode, a typical QR code reader tries to interpret a byte sequence as text encoded in UTF-8 or ISO/IEC 8859-1. Thus, QR codes cannot be used to encode arbitrary binary data directly. Such data has to be converted into an appropriate text before that text could be encoded as a QR code. Compared to already established Base64, Base32, and Base16 encoding schemes that are described in [RFC4648], the Base45 scheme described in this document offers a more compact QR code encoding.

One important difference from those others and Base45 is the key table and that the padding with '=' is not required.

2. Conventions Used in This Document

The key words "**MUST**", "**MUST NOT**", "**REQUIRED**", "**SHALL**", "**SHALL NOT**", "**SHOULD**", "**SHOULD NOT**", "**RECOMMENDED**", "**NOT RECOMMENDED**", "**MAY**", and "**OPTIONAL**" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

3. Interpretation of Encoded Data

Encoded data is to be interpreted as described in [RFC4648] with the exception that a different alphabet is selected.

4. The Base45 Encoding

QR codes have a limited ability to store binary data. In practice, binary data have to be encoded in characters according to one of the modes already defined in the standard for QR codes. The easiest mode to use in called Alphanumeric mode (see Section 7.3.4 and Table 2 of [ISO18004]. Unfortunately Alphanumeric mode uses 45 different characters which implies neither Base32 nor Base64 are very effective encodings.

A 45-character subset of US-ASCII is used; the 45 characters usable in a QR code in Alphanumeric mode (see Section 7.3.4 and Table 2 of [ISO18004]). Base45 encodes 2 bytes in 3 characters, compared to Base64, which encodes 3 bytes in 4 characters.

For encoding, two bytes [a, b] **MUST** be interpreted as a number n in base 256, i.e. as an unsigned integer over 16 bits so that the number n = (a * 256) + b.

This number n is converted to base 45 [c, d, e] so that n = c + (d * 45) + (e * 45 * 45). Note the order of c, d and e which are chosen so that the left-most [c] is the least significant.

The values c, d, and e are then looked up in Table 1 to produce a three character string. The process is reversed when decoding.

For encoding a single byte [a], it **MUST** be interpreted as a base 256 number, i.e. as an unsigned integer over 8 bits. That integer **MUST** be converted to base 45 [c d] so that a = c + (45 * d). The values c and d are then looked up in Table 1 to produce a two-character string.

A byte string [a b c d ... x y z] with arbitrary content and arbitrary length **MUST** be encoded as follows: From left to right pairs of bytes **MUST** be encoded as described above. If the number of bytes is even, then the encoded form is a string with a length that is evenly divisible by 3. If the number of bytes is odd, then the last (rightmost) byte **MUST** be encoded on two characters as described above.

For decoding a Base45 encoded string the inverse operations are performed.

4.1. When to Use and Not Use Base45

If binary data is to be stored in a QR code, the suggested mechanism is to use the Alphanumeric mode that uses 11 bits for 2 characters as defined in Section 7.3.4 of [ISO18004]. The Extended Channel Interpretation (ECI) mode indicator for this encoding is 0010.

On the other hand if the data is to be sent via some other transport, a transport encoding suitable for that transport should be used instead of Base45. For example, it is not recommended to first encode data in Base45 and then encode the resulting string in Base64 if the data is to be sent via email. Instead, the Base45 encoding should be removed, and the data itself should be encoded in Base64.

4.2. The Alphabet Used in Base45

The Alphanumeric mode is defined to use 45 characters as specified in this alphabet.

Value	Encoding	Value	Encoding	Value	Encoding	Value	Encoding
00	0	12	C	24	O	36	Space
01	1	13	D	25	P	37	$
02	2	14	E	26	Q	38	%
03	3	15	F	27	R	39	*
04	4	16	G	28	S	40	+
05	5	17	H	29	T	41	-
06	6	18	I	30	U	42	.
07	7	19	J	31	V	43	/
08	8	20	K	32	W	44	:
09	9	21	L	33	X		
10	A	22	M	34	Y		
11	B	23	N	35	Z		

Table 1: The Base45 Alphabet

4.3. Encoding Examples

It should be noted that although the examples are all text, Base45 is an encoding for binary data where each octet can have any value 0-255.

Encoding example 1:

The string "AB" is the byte sequence [[65 66]]. If we look at all 16 bits, we get 65 * 256 + 66 = 16706. 16706 equals 11 + (11 * 45) + (8 * 45 * 45), so the sequence in base 45 is [11 11 8]. Referring to Table 1, we get the encoded string "BB8".

AB	Initial string
[[65 66]]	Decimal value
[16706]	Value in base 16
[11 11 8]	Value in base 45
BB8	Encoded string

Table 2: Example 1 in Detail

Encoding example 2:

The string "Hello!!" as ASCII is the byte sequence [[72 101] [108 108] [111 33] [33]]. If we look at this 16 bits at a time, we get [18533 27756 28449 33]. Note the 33 for the last byte. When looking at the values in base 45, we get [[38 6 9] [36 31 13] [9 2 14] [33 0]], where the last byte is represented by two values. The resulting string "%69 VD92EX0" is created by looking up these values in Table 1. It should be noted it includes a space.

Hello!!	Initial string
[[72 101] [108 108] [111 33] [33]]	Decimal value
[18533 27756 28449 33]	Value in base 16
[[38 6 9] [36 31 13] [9 2 14] [33 0]]	Value in base 45
%69 VD92EX0	Encoded string

Table 3: Example 2 in Detail

Encoding example 3:

The string "base-45" as ASCII is the byte sequence [[98 97] [115 101] [45 52] [53]]. If we look at this two bytes at a time, we get [25185 29541 11572 53]. Note the 53 for the last byte. When looking at the values in base 45, we get [[30 19 12] [21 26 14] [7 32 5] [8 1]] where the last byte is represented by two values. Referring to Table 1, we get the encoded string "UJCLQE7W581".

base-45	Initial string
[[98 97] [115 101] [45 52] [53]]	Decimal value

[25185 29541 11572 53]	Value in base 16
[[30 19 12] [21 26 14] [7 32 5] [8 1]]	Value in base 45
UJCLQE7W581	Encoded string

Table 4: Example 3 in Detail

4.4. Decoding Example

Decoding example 1:

> The string "QED8WEX0" represents, when looked up in Table 1, the values [26 14 13 8 32 14 33 0]. We arrange the numbers in chunks of three, except for the last one which can be two numbers, and get [[26 14 13] [8 32 14] [33 0]]. In base 45, we get [26981 29798 33] where the bytes are [[105 101] [116 102] [33]]. If we look at the ASCII values, we get the string "ietf!".

QED8WEX0	Initial string
[26 14 13 8 32 14 33 0]	Looked up values
[[26 14 13] [8 32 14] [33 0]]	Groups of three
[26981 29798 33]	Interpreted as base 45
[[105 101] [116 102] [33]]	Values in base 8
ietf!	Decoded string

Table 5: Example 4 in Detail

5. IANA Considerations

This document has no IANA actions.

6. Security Considerations

When implementing encoding and decoding it is important to be very careful so that buffer overflow or similar issues do not occur. This of course includes the calculations in base 45 and lookup in the table of characters (Table 1). A decoder must also be robust regarding input, including proper handling of any octet value 0-255, including the NUL character (ASCII 0).

It should be noted that Base64 and some other encodings pad the string so that the encoding starts with an aligned number of characters while Base45 specifically avoids padding. Because of this, special care has to be taken when an odd number of octets is to be encoded. Similarly, care must be taken if the number of characters to decode are not evenly divisible by 3.

Base encodings use a specific, reduced alphabet to encode binary data. Non-alphabet characters could exist within base-encoded data, caused by data corruption or by design. Non-alphabet characters may be exploited as a "covert channel", where non-protocol data can be sent for nefarious purposes. Non-alphabet characters might also be sent in order to exploit implementation errors leading to, for example, buffer overflow attacks.

Implementations **MUST** reject any input that is not a valid encoding. For example, it **MUST** reject the input (encoded data) if it contains characters outside the base alphabet (in Table 1) when interpreting base-encoded data.

Even though a Base45-encoded string contains only characters from the alphabet in Table 1, cases like the following have to be considered: The string "FGW" represents 65535 (FFFF in base 16), which is a valid encoding of 16 bits. A slightly different encoded string of the same length, "GGW", would represent 65536 (10000 in base 16), which is represented by more than 16 bits. Implementations **MUST** also reject the encoded data if it contains a triplet of characters that, when decoded, results in an unsigned integer that is greater than 65535 (FFFF in base 16).

It should be noted that the resulting string after encoding to Base45 might include non-URL-safe characters so if the URL including the Base45 encoded data has to be URL-safe, one has to use percent-encoding.

7. Normative References

[ISO18004] ISO/IEC, "Information technology - Automatic identification and data capture techniques - QR Code bar code symbology specification", ISO/IEC 18004:2015, February 2015, <https://www.iso.org/standard/62021.html>.

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